Integrating Trees into the Design of the City: Expert Opinions on Developing More Sustainable Practices for Planting Street Trees in Australian Cities.

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Abstract

Street trees provide cities with a range of social, economic and environmental benefits, with large, mature trees providing the maximum benefits. Street trees can be conceptualized as a form of ‘green infrastructure’, delivering a range of environmental and human services alongside the ‘grey infrastructure’ of conventional engineering services. However street trees face an extremely hostile environment in the city and may struggle to survive and grow. These challenges are exacerbated by ‘unsustainable’ streetscape design and tree planting practices, such as planting trees in undersized tree pits dug in compacted urban soils, and surrounding trees with hard impervious surroundings. These practices often result in declining tree health, reduced tree life spans, increased tree mortality and also conflicts between trees and surrounding infrastructure.

This thesis aims to develop a more sustainable model for urban streetscape design and street tree planting practices in Australian cities, which better integrates the needs of street trees, based on the expert opinions of researchers and practitioners in the field. A mixed-method research strategy was adopted, using both quantitative and qualitative techniques. A detailed literature review of current tree planting practices was undertaken covering the following topics: providing space both above and below ground; providing trees with the resources for growth; and minimizing a range of infrastructure conflicts. The views of a variety of professionals across Australia were then collected using various techniques. These included an Australia-wide online survey of local government practitioners to address the wider picture, and in-depth interviews with practitioners in metropolitan Adelaide, to provide a detailed understanding of the issues. Detailed case studies were also conducted in four Australian capital cities, including interviews with local luminaries, to review current ‘best practice’ techniques and policies for street tree planting.

The outcome of this research is presented as a new paradigm for the more sustainable urban tree planting and management practices, entitled ‘Tree Sensitive Urban Design’ (TSUD). A proposed “Model for TSUD” draws upon the practices identified in the thesis research, and recommends that the management of urban trees should move from an engineering-based approach to streetscape design, to considering street trees as an essential part of the city. The ‘Model for TSUD’ presented includes a set of objectives, planning and design principles, and a set of ‘structural’ and ‘non-structural’ best practices to accommodate street trees.

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Declaration

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Acknowledgements

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1 Introduction

1.1 The research problem

The problem

> *It is time to make some changes in the design and construction of our cities. Trees are a major element in the city structure with their own economic, ecological, and aesthetic values. Because they are living components, we need to pay attention to the air, water, and space they need to grow-both above and below ground. Just planting more trees is not the answer. Trees have long been fit into spaces left over after everything else is written into the design. This approach will not work if we want our trees to be a major element in the city's structure* (1989 p.94).

Street trees provide a wide range of social, economic and environmental benefits to the city. They can in fact be seen as a form of 'green infrastructure', delivering human and environmental services, alongside the 'grey infrastructure' of conventional engineering services. It has also been shown that large, mature trees deliver the greatest benefits.

Street trees, therefore, should be allowed to survive and grow to maturity to maximize their benefits. Trees, however, face an extremely hostile environment in the city, both above and below ground. Some of the main concerns are in what has been called the 'landscape below ground' where trees must survive in highly modified and compacted 'urban soils'. This already hostile environment is further exacerbated by inappropriate and unsustainable planting practices. Trees are often planted in undersized tree pits excavated in compacted soils, and surrounded by hard impervious surfaces that limit soil moisture and aeration. The consequences are undesirable, for both the tree and the city. These consequences include declining tree health, reduced life span and increased mortality, as well as conflicts with surrounding urban infrastructure. Management responses to these issues often involve further unsustainable practices such as tree removal, increased tree maintenance inputs, and increased infrastructure maintenance and repair. In times of drought, climate change, and increasing urban densification, street trees will face an increasingly hostile environment. At the same time the benefits delivered by street tees will become increasingly important to the city.

It is a fundamental fact that, if trees are to survive, their essential biological requirements must be met. The biological needs of trees in the city are, in fact, the same as those in their native habitat. The requirements of oxygen, carbon dioxide, light, water, nutrients, and appropriate temperatures must be met, to sustain the essential processes of photosynthesis, respiration and transpiration. Above all, trees need adequate space to grow, both above and below ground. In the last decade or so, arborists and others have developed a better understanding of the interactions between tree roots, soil, and water, in urban settings. However, the other disciplines involved in the design of urban streetscapes (including planners, engineers, designers, and asset managers), may not be fully aware of the biological tree needs that must be accommodated in the design process.

The need for research

Street trees are more than aesthetic decoration. They are in fact an essential and valuable part of the city. It is not just a case of 'wanting' trees, but of 'needing' trees in our cities. Many of the issues raised above are a consequence of failing to understand or recognize the biological needs of trees. It is suggested, therefore, in this dissertation and its conclusions, that when designing urban streets to accommodate trees, we should adopt a 'tree literate' approach to design, and in fact try to 'think like a tree'.

The aim of this thesis, therefore, is to develop a model for urban streetscape design which better integrates the needs of street trees into both the design process, and the physical fabric of the city. Such a model would have two main aims: to promote improved street tree health and longevity; and to reduce conflicts between street trees and their surrounding infrastructure. It would include a set of principles and 'best management practices', and importantly would have a strong interdisciplinary focus, as successful streetscape design incorporating tree planting must be a collaboration between the separate disciplines of engineering, science and design. As eminent United States soil scientist Philip Craul has said:

> *Landscape design is an interdisciplinary art and science. When the best of art is coupled with sound science and application of appropriate technology a successful design results. This goal can be accomplished through the mutual interaction of the landscape architect, scientist and engineer. Too often, lack of funds or failure to appreciate the interaction prevents designs from being successful. There are many more examples of successful designs than there are failures. We should learn from both types of examples* (Craul 1992 p.361).

The thesis will further address extent of the problem and the need for further research to develop a model for more sustainable practices. Previous studies that have addressed the issue have tended to have a strong arboricultural, rather than interdisciplinary focus. There has also been only limited dissemination of current arboricultural knowledge in the landscape architecture and urban planning literature. One notable exception is the writings and practice of United States landscape architect James Urban who has been long term champion of improved urban tree planting practices. There has also been an emphasis on settings and practices in the United States, and to a lesser extent northern Europe, which are not necessarily transferable to a unique Australian context. The thesis also places an emphasis upon qualitative research, aimed at developing an in-depth understanding of issues, which has only been addressed to a limited extent in arboricultural literature.

The thesis addresses a real world need for more sustainable practices. While the thesis will be of use to arborists and tree managers, it is primarily aimed at a non-arboricultural audience, at urban designers, landscape architects, engineers, urban planners and asset managers who play a role in the different stages of the streetscape design process, and can influence the success or otherwise of street tree planting. The thesis aims to review and reinterpret current arboricultural and related knowledge for that wider audience. The original research component addresses the Australian context, to develop an understanding of local issues and practices. It is intended that the research will have real world applications and contribute to the adoption of improved street tree planting and streetscape design practices and to a greater recognition of the role of trees by public policy makers.

1.2 Research questions

The purpose of the study is to explore strategies and practices involved in the design of urban streetscapes to accommodate street trees, and from that understanding to develop a theoretical framework or model for more sustainable practices. The research will have particular application to an Australian context, and will be of use to the different participants in the streetscape design process, including a non-arboricultural audience of designers, engineers, planners and asset managers.

Central question

What practices should be adopted to better accommodate the needs of trees in the design of urban streetscapes?

Sub-questions

How can the recognized benefits of street trees be maximized?
What are the key issues and problems associated with street trees?
What are the constraints on tree planting in urban streets?
What are the emerging threats to street trees both now and in the future?
What are the biological needs of trees, to be accommodated in the design process?
What practices can be adopted to grow healthier, longer lived street trees?
What practices can be adopted to minimize street tree/infrastructure conflicts?
How can these practices be integrated into a more sustainable 'tree literate design' model?

1.3 Study limitations

The study addresses a very broad and multi-disciplinary topic. It has been necessary to narrow the scope of the study to focus on specific components of the broader topic. Table 1 identifies the items that were addressed, or not addressed in, the design of the research strategy. However, as qualitative research is, by its nature exploratory and open ended, these factors were addressed if raised by participants (Creswell 2009).

Table 1: Research Focus

Primary research focus	Secondary research focus
Trees	Other vegetation types
Streets	Other urban spaces (e.g. squares)
Street trees	Other urban trees (e.g. park trees)
Trees in the public domain	Trees on private property
Urban settings	Rural and regional settings
Retrofitting existing streets	Green-field situations
Tree planting phase	Broader tree planting and management strategies
Landscape architecture focus	Arboricultural, engineering focus
Local government practices	State government, developer practices
Opinions of expert researchers and practitioners	Experimental research

The research focus was specifically about the practices involved in the planting of new trees in urban streets. It also focused on the activities of local government agencies, being the main bodies responsible for the implementation of urban tree planting and streetscape improvements. A landscape architecture, rather than arboricultural focus was also adopted, reflecting the author's background as an urban designer and landscape architect.

A key limitation was the study methodology, which was based on developing practice knowledge through research into the opinions of experts in the field. This is an alternative to the more traditional quantitative techniques often employed in arboricultural research, such as experimental plantings and field trials to investigate specific practices. Once again the methodology reflected the author's background in design and social sciences rather than arboricultural science.

Other research limitations identified included: ability to access to data in unpublished consultancy reports; ability to gain access to key street tree luminaries; and, a possible United States bias in the published literature.

1.4 Thesis structure

The thesis is presented in the following structure. Chapter 2 describes the research methodology adopted to undertake the study. Chapter 3 places the research topic within its broader interdisciplinary context. Chapters 4-5 provide an overview of street tree benefits, street tree issues, and biological tree needs. Chapters 6-8 comprise a literature review of current and emerging best practices in streetscape design to accommodate street trees. Topics addressed in Chapter 6 include above-ground design, below-ground design and water management. Chapter 7 examines street tree/infrastructure conflicts including hardscapes, buildings and services. Chapter 8 provides an overview of emerging practices in the field of Water Sensitive Urban Design (WSUD). Chapters 9-11 comprise the original research components of the study. Chapter 9 describes a case study of current 'best practices' in four Australian capital cities. Chapter 10 documents an Australia-wide online survey of local government street tree practitioners. Chapter 11 presents the findings of in-depth interviews with street tree practitioners in metropolitan Adelaide Councils. A 'Model for Sensitive Urban Design' is presented in Chapter 12, based on the findings of the literature review and original research component. Chapter 13 comprises the final discussion and conclusions of the thesis.

2 Methodology

2.1 Research strategy

Creswell identifies three main strategies of inquiry in research design: quantitative; qualitative and mixed-method. Each strategy is associated with specific methods of data collection and analysis (Creswell 2009).

In traditional quantitative strategies a research question is formulated, and much time is devoted to creating scales that adequately measure the research question (McLean *et al.* 2007). Quantitative strategies include experimental designs and non-experimental designs such as surveys, with the intent of generalizing from a sample to a wider population (Babbie 1990). Quantitative research includes correlation research which focuses on the relationships between real world variables that can be measured in some way (Groat & Wang 2002). Quantitative data is also usually in numerical form. A criticism of quantitative research is that it may limit understanding of the social phenomenon being investigated (McLean *et al.* 2007).

Qualitative research is a more recent research strategy, which has been prominent in the fields of psychology, sociology, education and nursing, and has been discovered by researchers in other fields in the last twenty years (Miles & Huberman 1994). Qualitative strategies allow a researcher to investigate an issue in some depth, or to discover the meaning of a phenomenon (McCaslin & Scott 2003). Qualitative strategies tend to approach the field of research without an hypothesis to prove or disprove. The focus is on understanding the phenomenon and potentially creating new knowledge. The research question provides a guide to the study and does not limit data collection and analysis. As data emerge they may suggest information that expands or narrows the original question (McCaslin & Scott 2003). Qualitative data is usually in the form of words, phrases and quotations rather than numbers.

Qualitative strategies can take a number of forms including narratives, phenomenologies, ethnographies, grounded theory and case studies (Creswell 2009). In grounded theory the researcher attempts to derive a theory grounded in, and emerging from, the views of the study participants, through an ongoing process of data collection and category refinement (Strauss & Corbin 1998). A distinguishing feature of grounded theory is an open-ended, iterative process of simultaneous data collection, analysis (coding), and theory building ('memoing') (Groat & Wang 2002). In a case study approach the researcher explores an activity in-depth, collecting detailed information over a defined period of time (Stake 1995). A key aspect of case-study research is its focus on studying a phenomenon embedded in its real world context (Groat & Wang 2002). Case study strategies can be exploratory, descriptive or explanatory in purpose (Yin 2003).

A recent paper noted the absence of qualitative research in the urban forestry literature, and the potential for its use in examining a range of urban forestry issues (McLean *et al.* 2007). From 2002-2004 only three of 125 articles in the *Journal of Arboriculture* used qualitative methodologies. The researchers concluded therefore, that quantitative research could provide deeper understanding in the four main themes identified in recent urban forestry literature: economic costs and benefits; ecological and environmental benefits; social benefits and perceptions; and urban forestry policy.

Mixed-method strategies recognize that all methods have inherent limitations and that a combination of methods may help to neutralize the potential bias or weakness in each. In this context reference is often made to the 'triangulation' of data sources (Groat & Wang 2002). Quantitative research, including survey methodologies, has the advantage of enabling the researcher to collect an extensive amount of information from a large number of respondents in a limited time. However this may come at the cost of a lack of in-depth understanding of the issues surveyed. Qualitative research, on the other hand, can add depth of understanding. However this may present challenges in dealing with vast quantities of information (Groat & Wang 2002).

According to Groat and Wang

> *Increasingly, researchers in many fields, including architecture, are advocating a more integrative approach to research whereby multiple methods from diverse traditions are incorporated in one study* (Groat & Wang 2002 p.361).

Creswell (2009) identifies three general strategies for mixed-method research: sequential; concurrent; and transformative. In a sequential strategy the researcher seeks to elaborate or expand the findings of one method with another.

> *This may involve beginning with a qualitative method for explanatory purposes and following up with a quantitative method with a large sample so the researcher can generalize results to a population. Alternatively the study may begin with a quantitative method in which theories and concepts are tested, to be followed by a qualitative method involving detailed exploration with a few cases or individuals* (Creswell 2003 p.16).

A mixed-method research strategy was considered to be most appropriate for this study, incorporating both quantitative and qualitative components. A sequential approach was adopted, comprising three discrete stages. Initial qualitative case-study research was undertaken for a pilot 'scoping' of issues. This was followed by quantitative survey research to examine the attitudes of a wider population. Finally qualitative in-depth interviews were undertaken within a defined area to gain a deeper understanding of those issues.

2.2 Research methods

As shown in Table 2, Creswell (2009) summarizes the specific methods of data collection and analysis for quantitative, qualitative and mixed method strategies.

Table 2: Quantitative, Mixed and Qualitative Methods

Quantitative Methods	Mixed Methods	Qualitative Methods
Pre-determined	Both pre-determined and emerging methods	Emerging methods
Instrument based questions	Both open- and closed-ended questions	Open-ended questions
Performance data, attitude data, observational data, and census data	Multiple forms of data drawing on all possibilities	Interview data, observation data, document data, and audio-visual data
Statistical analysis	Statistical and text analysis	Text and image analysis
Statistical interpretation	Across databases interpretation	Themes, patterns interpretation
Source: Creswell (2009) p.15.		

Quantitative research is characterized by the use of predetermined instruments of data collection, with closed ended questions, producing numerical statistical data. Data collection variables can be measured in terms of: categories; ordinal scales; or interval and ratio scales. Sampling is a key consideration, if the aim is to predict responses of a larger population, based on the patterns identified in a smaller subset (Groat & Wang 2002).

Qualitative research, however, tends to use open ended questions, producing text or image data, and with themes developing and emerging from the data. Mixed methods research combines the emerging and predetermined approaches, uses both open and closed ended questions, and produces both qualitative and quantitative data (Creswell 2009).

Creswell provides a useful list of the characteristics of qualitative research (Creswell & Plano Clark 2007).

- Qualitative research occurs in natural settings, where participants experience the issue under study (Groat & Wang 2002).
- The researcher is a key instrument in data collection, even where a data collection protocol is used (Miles & Huberman 1994).
- Quantitative researchers typically gather multiple sources of data, rather than a single data source (Groat & Wang 2002). The researcher then organizes the data into themes that cut across all of the data sources.
- Data analysis is inductive, building themes from the data, with the researcher organizing data into increasingly more abstract categories.

- The researcher focuses on learning the meaning that participants hold about the issues, rather than the meaning the researcher brings to the research (Groat & Wang 2002).
- The research process is emergent, and the processes may change as the researcher enters the field and collects data. 'The key idea behind qualitative research is to learn about the problem or issue from the participants and to address the research to obtain that information.'(Creswell 2009 p.176).
- Qualitative research is a form of interpretive inquiry in which researchers make an interpretation of what they observe (Groat & Wang 2002).
- Qualitative researchers try to develop a holistic, complex picture of the issue under study, reporting multiple perspectives and identifying the many factors involved in a situation (Miles & Huberman 1994). Visual models may assist in communicating this holistic picture.

The researcher's role in the qualitative process also creates a range of ethical and strategic issues. Inquirers therefore need to explicitly identify their background, biases and values (Creswell 2009). In this study the researcher is a landscape architect and urban designer, and potentially brings 'pro-tree' biases to the study, as well as viewing tree related issues through a 'design' lens.

2.3 Staging of the study

The study was undertaken in the following stages

1. Literature review
2. Original research
    a. Australian Capital Cities Study
    b. National Practitioner Study
    c. Metropolitan Adelaide Study
3. A Model for Tree Sensitive Urban Design (TSUD)

Table 3 provides a comparison of the three original research components of the study.

Table 3: Comparison of research studies

	Australian Capital Cities Study	National Practitioner Study	Metropolitan Adelaide Study
Research strategy	Qualitative	Quantitative	Qualitative
Objectives	Exploratory scoping of issues and practices in highly urbanized settings.	Nationwide snapshot of attitudes and practices.	In-depth exploration of issues. Detailed profile of attitudes and practices for a defined region.
Methodology	Case studies.	Online survey. Closed and open ended questions.	In-depth interviews.
Geographic scope	Melbourne, Sydney, Brisbane, Perth.	Australia wide.	Metropolitan Adelaide.
Target organizations	Capital city Councils.	Local government authorities.	Metropolitan Councils.
Target participants	Street tree luminaries. Senior tree managers and urban designers.	Council staff-arborists, landscape architects, engineers, planners, others.	Senior tree managers-arborists or landscape architects.
Data collection method	Unstructured interviews in workplace. Site visits.	Online survey. Distributed via databases and online newsletters.	Structured interviews in workplace.
Data collection instrument	Researcher. Interview guide.	*Survey Monkey* web tool. Continuous and categorical scales. Open ended comments.	Interview protocol with set questions and open ended responses. Taping of interviews.
Data	Interview notes. Photographs. Documents.	Numerical data. Text.	Interview tapes. Interview notes. Verbatim interview transcripts.
Data presentation and analysis	Interview text. Images. Case study grids.	*Survey Monkey* tabulation of response. Descriptive tables and charts. Summaries of open ended responses.	Text. Analysis with *QSR XCite* program. Analysis frameworks, maps and grids.
Advantages	Exploration of a wide range of settings.	Extensive geographic spread. Time and cost effective. Provides a quick overview of the bigger picture.	Allows deeper understanding of issues.
Disadvantages	Gaining access to key personnel. Time and distance constraints.	Restrictions on questionnaire length limit range of questions and scope for responding. Bias towards responses from pro-tree individuals.	Time consuming in interviewing, transcribing and analyzing responses. Difficulty accessing busy key personnel.

2.4 Literature review

An extensive review of literature on the research topic was undertaken, and is presented in the following chapters 3-8. The literature review aimed to assess the current state of knowledge regarding ‘tree literate design’, gaps in the knowledge, opportunities for further research, and to provide a theoretical basis to inform the original research stages of the study.

The main body of knowledge is situated within the literature of arboriculture and urban forestry, especially from a United States perspective. The journal of the International Society of Arboriculture

(ISA), *Arboriculture and Urban Forestry,* (http://www.isa-arbor.com/members/joaSwitch.aspx) is a major international disseminator of arboricultural research and knowledge. The Northern European equivalent is *Urban Forestry and Urban Greening* (http://shop.elsevier.de/ufug). The United Kingdom journal of the British Arboricultural Association, *The Arboricultur*al *Journal* (http://www.trees.org.uk/journal.php), is a more localized publication. In Australia the TREENET organization has been organizing annual Symposia since 2000 and publishing the proceedings (http://www.treenet.com.au/symposium), which provide a valuable overview of arboricultural knowledge from an Australian perspective. Due to the nature of the research topic, relevant knowledge is also spread over a wide range of other scholarly journals, including the fields of plant science, soil science, climatology and hydrology.

The past ten to twenty years have seen significant advances in arboricultural knowledge, including an increased awareness the interactions of trees, soil and water in urban settings. A number of key reference texts have been produced including the pioneering works of Alex Shigo, *A New Tree Biology* (Shigo 1986) and *Modern Arboriculture* (Shigo 1991). Philip Craul has written the definitive texts on urban soils including *Urban Soils in Landscape Design* (Craul 1992), *Urban Soils: Applications and Practices* (Craul 1999), and *Soil Design Protocols for Landscape Architects and Contractors* (Craul & Craul 2006). Other significant publications which raised awareness of urban tree issues include *Trees for Urban and Suburban Landscapes* (Gilman 1997), *Principles and Practices of Planting Trees and Shrubs* (Watson & Himelick 1997), *Trees and Development* (Matheney & Clark 1998) and the definitive textbook *Arboriculture* (Harris 1983), published in a number of editions since 1983.

Knowledge of tree root biology and interactions with urban soils has also expanded dramatically over the last decade, with a new emphasis on the 'landscape below ground'. Landmark events in this new awareness have included two international *Landscape Below Ground* workshops on *Tree Root Development in Urban Soils* organized by the ISA in 1994 and 1998 (Watson & Neely 1994; Neely & Watson 1998). A third *Landscape Below Ground* workshop was also conducted in 2009 and published during the final stages of this thesis (Watson *et al.* 2009). A symposium in 2000 at the University of California, Davis, highlighted the current state of knowledge regarding conflicts between tree roots and urban infrastructure (Costello *et al.* 2000). The findings were published as a handbook *Reducing Infrastructure Damage by Tree Roots: A Compendium of Strategies* (Costello & Jones 2003). Most recent texts include *Trees in the Urban Landscape* (Trowbridge & Bassuk 2004), and the UK handbook *Tree Roots and the Built Environment* (Roberts, Jackson & Smith 2006).

A number of texts have also addressed tree management from the perspective of the 'urban forest'. These include *Shading our Cities* (Moll & Ebenreck 1989), the 1988, 1997 and 2007 editions of

Urban Forestry by Miller (Miller 2007), and *Urban Forest Landscapes: Integrating Multidisciplinary Perspectives* (Bradley 1995). Urban forestry is also a recognized discipline in areas other than the United States, including northern Europe (Konijnendijk 2008).

Despite the extent of recent arboricultural literature on urban trees, urban and landscape design considerations tend to be given a somewhat superficial treatment. This is apparent in two main areas. Firstly there is little emphasis on the more intangible, and less easily quantified, visual and aesthetic benefits of street trees; and secondly a limited treatment of the development of urban design solutions to enhance the growing environment for street trees. These limitations are to an extent inherent in the nature of science based arboricultural research and practice.

Conversely, the scholarly literature on urban planning, urban design, and landscape architecture, provides only limited coverage of innovations in arboricultural practice, beyond the recognition of trees as significant design elements in the city. There have, however, been a number of significant books produced by practicing landscape architects. Henry Arnold's 1980 book, *Trees in Urban Design*, addressed both visual design strategies, and the need for improved design of the below-ground space (Arnold 1980). Anne Whiston Spirn's seminal 1984 book, The *Granite Garden*, highlighted the problems facing trees in the city, and potential solutions (Spirn 1984a). In 1993 O'Brien summarized street tree benefits and issues, in a European and Australian context, in *Street Trees for Cities and Towns* (O'Brien 1993). Alan Jacob's 1993 book, *Great Streets*, highlighted the significant role of trees in creating high quality streetscapes (Jacobs 1993). A later book focused on the design of urban boulevards (Jacobs, MacDonald & Rofe 2002).

One area in which there has been a dialogue between design and arboriculture is in the field of sustainable landscape design. In *Cities and Natural Processes*, Michael Hough (2004) has extended the work of Spirn, considering urban trees as part of a complex 'urban ecology'. In both the 2000 and 2008 editions of *Sustainable Landscape Construction*, Thompson and Sorvig (2000; 2008) addressed urban tree issues, and the emerging design practices to create more favorable growing conditions in urban situations, including structural soils and root trench technologies. They recognized the contribution of United States landscape architect James Urban, who has been one of the most significant champions of urban trees, and the need for more innovative, science based design practices, in both his landscape architecture practice and his writings since around 1989. Most recently Urban (2008) has published a practical landmark text on urban trees, *Up by Roots*, aimed at bridging the gap between science and design. Urban's book addresses many of the research questions that are the subject of this thesis, but has a North American focus, and does not address some broader issues of concern such as Water Sensitive Urban Design (WSUD). Another landscape architect Bruce Ferguson has also produced a definitive text on permeable surfaces, *Porous Pavements,* which addresses design strategies to accommodate trees (Ferguson 2005).

From an Australian perspective, the annual TREENET[1] symposia, conducted in Adelaide since 1990, and published online, address many of the issues of concern over the last ten years, including arboricultural practice, urban soils and water management (http://www.treenet.com.au/symposium). Hitchmough's 1994 handbook, *Urban Landscape Management*, includes a detailed review of urban tree planting issues and practices from an Australian perspective (Hitchmough 1994). Local soil scientist Derek Handreck's textbook, *Growing Media for Ornamental Plants and Turf*, provides detailed information on plant-soil-water relationships, but with only limited coverage of urban trees (Handreck & Black 1989). A recent book, *Ecohydrology*, by Derek Eamus and others, examines tree-water inter-relationships, but primarily from an ecosystem viewpoint (Eamus e*t al.* 2006).

A literature search, however, showed that recent advances in arboriculture have received little attention in scholarly landscape architecture, urban design and urban planning journals. Some coverage is given in the multi-disciplinary journal *Landscape and Urban Planning*, (http://www.elsevier.com/wps/find/journaldescription.cws_home/503347/description) but little in the design focused *Landscape Journal* (http://lj.uwpress.org/).

The popular journal of the American Institute of Landscape Architects, *Landscape Architecture* (http://archives.asla.org/nonmembers/lam.html) while primarily showcasing recent project work, publishes frequent articles on advances on arboriculture and sustainable design practices. The equivalent publication of the Australian Institute of landscape Architects, *Landscape Architecture Australia*, (http://www.aila.org.au/landscapeaustralia/) focuses mainly on design projects.

The findings of the literature review are presented in Chapters 3-7. A key outcome is a summary of practices for above- and below-ground design, water management and infrastructure conflicts, which underlie the proposed Tree Sensitive Urban Design (TSUD) Framework.

2.5 Australian Capital Cities Study

Qualitative case studies were undertaken of street tree practices in four Australian capital cities. In capital cities street tree planting is often 'mandatory', while at the same time presenting some of the most extreme environments for tree planting. A detailed description of the study methodology and findings is presented in Chapter 8 .The cities of Melbourne, Sydney, Brisbane and Perth were visited and street tree 'luminaries' in each Council interviewed, using an open-ended, exploratory

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[1] TREENET is a not-for-profit organization funded by grants and voluntary contributions from participating Councils, nurseries and other groups (http://www.treenet.com.au/). The organization is based at the University of Adelaide's Waite Arboretum at Urrbrae South Australia.

approach. Examples of 'best practices' were visited with the study participants and photographed. The study output comprised a written description of issues in each city, recent project examples and a summary of practices being adopted. The written description was forwarded to each of the participants for comment and verification. Conclusions were drawn based on a comparison between the different cities.

2.6 National Practitioner Study

A quantitative survey was undertaken of the attitudes and practices of street tree practitioners employed in local government authorities throughout Australia. A detailed description of the study methodology and findings is presented in Chapter 9. Local government comprises the main tree planting and tree management agency in Australia. The intention was to obtain a descriptive Australia wide 'snapshot' of attitudes and practices. An online web-based questionnaire was administered using the *Survey Monkey* web tool. The survey findings were presented in the form of descriptive tabulation of data, and also open ended responses. Conclusions were drawn regarding key issues of concern, and the level of adoption of a range of practices, on a national basis.

2.7 Metropolitan Adelaide Study

A qualitative, in-depth study was undertaken of attitudes and practices by tree managers in twelve local government authorities in the metropolitan Adelaide region. A detailed description of the study methodology and findings is presented in Chapter 10. The study had two main intentions: to provide added meaning to the findings of the National Practitioner Study; and to provide a detailed profile of the attitudes and practices in a specific region of metropolitan Adelaide. Structured, in-depth interviews were conducted with tree managers in each of the twelve local government authorities comprising the region, addressing the same topics covered in the National Practitioner Study. Interviews were taped and transcribed, with the transcript approved by the participant. Transcript text was analyzed using the QSR XCite software program. The study findings were presented in the form of analysis frameworks, grids and quotations. Conclusions were drawn regarding attitudes and practices within the region.

2.8 A Model for Tree Sensitive Urban Design (TSUD)

The findings of the literature review, and the three original research studies, provide the basis for the draft Model for Tree Sensitive Urban Design (TSUD) presented in Chapter 11. The Model comprises a Vision Statement, Design Principles and Best Management Practices. It is intended that the Model would provide a consistent basis for tree management authorities and others to develop detailed strategies for their own specific areas.

3 Study context

3.1 Introduction

The aim of this section is to place the research topic within three broad fields of knowledge and practice: arboriculture and urban forestry; sustainability; and streetscape design.

3.2 Urban forestry

Arboriculture

In Australia, and the United States, street trees are generally planted, maintained and managed by municipal arboricultural staff (Miller 2007). Arboriculture is a specialized discipline within horticulture, focusing mainly on the planting and care of trees (Harris *et al.* 2004). The practice of arboriculture has evolved significantly in the past two decades, in two areas: the development of a more scientific understanding of urban trees and soils; and the development of the concept of 'urban forestry'. In addition, local government paradigms governing urban trees have evolved, along with other aspects of municipal management (Miller 2007).

In 1994 Hitchmough noted a 'quiet revolution' in arboricultural practice, from prescriptive nineteenth century practices, to practices based on a scientific understanding of tree biology (Hitchmough 1994). This has been reflected in a new generation of arboricultural literature (Harris 1983; Shigo 1986; Craul 1992; Gilman 1997; Watson & Himelick 1997; Matheney & Clark 1998).

Urban forestry

There has also been a shift in emphasis from the management of the individual tree, to a more holistic approach considering the tree in its wider context, and the emergence of the 'urban forestry' paradigm. The urban forest has been defined as

> *The sum of street trees, residential trees, park trees and greenbelt vegetation. It includes trees on unused public and private land, trees in transportation and utility corridors, and forests on watershed land. Some of these trees and forests were willfully planted and are carefully managed by their owners, while others are accidents of land use decisions, economics, topography and neglect* (Miller 2007 p.27).

The practice of urban forestry essentially involves the management of urban trees at a greater than individual basis (Harris *et al.* 2004). Rowntree (1984) identifies three factors determining urban forest structure: urban morphology (which creates space for trees); natural factors (which controls what can grow where); and management factors (which determine which species humans elect to plant and manage in the urban landscape). Other professions may also be involved in urban forestry, for example landscape architects and recreation planners. The related concept of 'urban ecology' sees the city as a habitat for people alongside vegetation, wildlife and built form (Moll & Petit 1994).

The concept of urban or community forestry has gained wide acceptance in the United States and Europe, and to a lesser extent in Australia. In response, in 2005 the *Journal of Arboriculture* was renamed *Arboriculture and Urban Forestry*, and the equivalent European journal is named *Urban Forestry and Urban Greening*.

Municipal forestry

Municipal forestry, as it is known in the United States, deals with the establishment and maintenance of trees and other vegetation, mainly on public land. Municipal forestry functions are located within local government authorities in a range of forms (Miller 2007). Municipal forestry programs include street tree programs, which generally aim to fully stock streets with trees, manage the tree over its life-cycle to maximize public benefits while minimizing costs and public risks, and finally removing and replacing the tree when it reaches the end of its useful life (Miller 2007). Ideally trees should be removed prior to decline and death, based on the relationship between diminishing aesthetic returns, and increasing management costs (Hitchmough 1994). Essentially, municipal forestry aims to achieve a stable street tree population that will not be threatened by catastrophic losses, and so will have a desired level of species and age diversity (Lobel 1983). Tree species selection is a key consideration, and a number of tree selection models have been developed which include physical, social and economic criteria (Clark & Kjelgren 1989; Hitchmough 1994; Trowbridge & Bassuk 2004). Some authorities develop detailed street tree master plans, while in others this may simply consist of a preferred tree species list (Miller 2007).

Many different individuals may be involved in the planting and long term management of a street tree, including tree growers and suppliers, landscape architects, arborists, maintenance staff and others (Thompson & Sorvig 2008). In a sense a street tree passes through a 'chain of custody' in terms of its propagation, planting and management (Lawry 2007). It is useful to envisage the management of a street tree in terms of its life-cycle, and the different inputs at each stage. For example Table 4 illustrates one such conceptualization from a United Kingdom perspective (Bradshaw *et al*. 1995).

Table 4: Tree life cycle considerations in stages of urban tree planting projects.

Stage of project	Components	Major factors
Idea	Conception of scheme	Use Human needs
Design	Scheme detailing	All factors
	Site conditions appraisal	Compaction Poverty Toxicity Topography
Contract	Contract preparation	All factors
Site preparation	Site treatment	Cultivation Drainage Soil cover Ground surfaces
Tree supply	Tree preparation Species Planting stock	Lifting Growing conditions Pruning Growth form Ecology Type
Planting	Planting Tree handling	Root damage Pit qualities Exposure
Establishment	Aftercare	Weeds Nutrients Water logging Drought
Maintenance	Site maintenance Protection	Mowing Tree guards Vandals Vehicles Stakes and ties
Monitoring	Occasional factors	Salt Air pollution Exposure Pest and disease
Source: Bradshaw *et al.* (1995) p.1.		

Municipal forestry programs, in the United States and Australia, have experienced changes over the last century, with changes in community priorities (Miller 2007). Norris reviews the different approaches available for urban tree management from an Australian perspective, each associated with a different set of implicit values (Norris 2005). Table 5 summarizes Norris's analysis.

Table 5: Street tree management approaches

NOTE:
This table is included on page 18 of the print copy of the thesis held in the University of Adelaide Library.

Source: Based on material from Norris (2005).

Norris concludes that the policy drivers for street tree management have evolved from the aim of creating urban amenity, to the current emphasis on risk management, which may limit tree planting options. In the future the main policy driver is likely to be asset management involving the full life cycle management of trees alongside other urban assets. In the past, street trees have also fallen within the engineering and works function of local government authorities, and many past tree/infrastructure conflicts have resulted from engineer's functional view of trees and their lack of biological knowledge. However an emerging approach is to recognize the value of both 'grey' and 'green' infrastructure (Foster 2003).

3.3 Sustainability

Definitions

The term 'sustainability', has emerged in the last few decades as a broad set of principles addressing social, economic and environmental development at almost any scale (Watson 2007a). However, despite its widespread use the term does not have an agreed definition, and to some extent has become a 'buzzword' to market a range of products (Thompson & Sorvig 2008). At its core, it refers to the ability to manage a system (social, economic or environmental) so as to perpetuate it indefinitely without compromising the ability to continue to do so in the future (Johnson & Hill 2002).

The current widespread use of the term is in the context of 'sustainable development'. The concept and its history will not be discussed in detail here[2], however it originated in the Stockholm Conference on the Human Environment in 1972, appeared in the World Conservation Strategy in 1980, and came of age in the 1987 Brundtland Commission Report, *Our Common Future* (Thompson 2000). The popularly quoted definition used in the latter was development that '…meets the needs of the present without diminishing the ability of future generations to meet their own needs' (WCED 1990 p.8). The scope of the term was enlarged at the United Nations 1992 Earth Summit in Rio de Janiro to address global development policies including issues of poverty, resource imbalance and imbalances in global development. The Rio Earth Summits Agenda 21 produced a well known set of sustainability principles adopted by many governments, including local government authorities in Australia.

Sustainability as a concept, however, has much earlier roots than the relatively recent concept of sustainable development. Its environmental and ethical basis originates from ecology, evident in the writings of Aldo Leopold in his 1948 classic *The Land Ethic*, which proposed an ecological approach to land and landscapes (Leopold 1948). The term was also applied to forestry and agriculture in the 1970s to describe management policies which maintain natural resource capacity (Benson & Roe 2000). The concept of 'sustained yield' is used by foresters and others (including fishery and water resource managers) to define a harvestable surplus that can be indefinitely maintained, without reducing the productive capital. However sustainable yield can be difficult to quantify because of the dynamic nature of ecological systems and the role of other non-harvesting factors which affect both the natural capital and its productivity. A related concept is that of permaculture, an approach to designing human settlements and agricultural systems that mimic natural ecologies. Permaculture was developed by Australians Bill Mollison and David Holmgren in the 1970's and aims to achieve 'permanent', self-sufficient and stable agricultural and cultural systems, through training in a core set of design principles (Mollison 1988). While originating as an agro-ecological design theory, permaculture has grown into a wider value system for sustainable human settlements (Holmgren 2002).

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[2] For a detailed historical, theoretical and applied research discussion of sustainability in a design context, see Williamson, T., A. Radford and H. Bennetts (2003). Understanding Sustainable Architecture. London, Spon Press.

The design professions have also embraced the concept of sustainability, with the roots of 'sustainable design' in the 'ecological design' movement[3], which emerged in the United Kingdom in the mid-twentieth century in the work of Brenda Colvin, Sylvia Crowe and Simon Hackett, and in the United States in the work of Ian McHarg (Benson & Roe 2000). In 1979 Ian McHarg published his seminal book on ecological design at the regional scale, *Design with Nature*, (McHarg 1979), and in 1984 Anne Whiston Spirn applied ecological principles to the city in *The Granite Garden* (Spirn 1984a). In the 1980's writers such as John Lyle suggested that sustainability alone was not sufficient, and that designed ecosystems should be 'regenerative' and capable of renewing energy and materials, rather than 'degenerative' (Lyle 1994). Other writers have addressed the relationship between sustainable landscapes, landscape aesthetics and community preferences (Thayer 1989).

Sustainable landscapes

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

> *Contribute to human well-being and at the same time are in harmony with the natural environment. They do not deplete or damage other ecosystems. While human activity will have altered native patterns, a sustainable landscape will work with native conditions in its structure and functions. Valuable resources-water, nutrients, soil etcetera, and energy will be conserved, diversity of species will be maintained or increased* (Thompson & Sorvig 2000 p.3).

Perry (1995) has proposed a number of goals to develop and maintain sustainable landscapes. Similar goals are proposed by Thompson and Sorvig (Thompson & Sorvig 2008). In South Australia the 'Sustainable Landscapes Project'[4] defines eight criteria for sustainable landscapes. Such goals and principles typically include: local contextual design; selection of plants suited to local conditions; use of non-invasive plant species; reduced resource inputs of energy and materials; water conservation; enhanced biodiversity and habitat creation; and avoidance of harmful chemicals.

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[3] For a detailed discussion of sustainability from a landscape design perspective see Benson, J. F. and M. H. Roe, Eds. (2000). Landscape and Sustainability. London and New York, Spon Press.

[4] The Sustainable Landscapes Project is a collaboration between various government agencies in South Australia aimed at promoting sustainable landscape design (http://www.environment.sa.gov.au/botanicgardens/programs/landscapes.html). A sustainable landscape is defined as 'a healthy and resilient landscape that will endure over the long term without the need for high input of scarce resources such as water. The natural functions and processes of the landscape are able to maintain it into the future'.

A common goal is for landscapes' …that conserve, recycle, and reuse resources to achieve optimal levels of sustainability' (Perry 1995 p.176). A useful way to consider the sustainable use of resources, such as water, materials, and energy, is to consider designed landscapes as functioning systems with inputs, outputs and internal cycling. Unsustainable systems tend to be 'open' with high resource inputs, minimal internal recycling, and high outputs of waste and energy. More sustainable systems will be more 'closed', with reduced inputs of materials and energy, a high level of internal recycling, and reduced waste outputs (Dunnett & Clayden 2000).

Sustainable urban forestry

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

> *The naturally occurring and planted trees in cities which are managed to provide the inhabitants with a continuing level of economic, social, environmental and ecological benefits today and into the future* (Clark *et al.* 1997 p.21).

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

In the United States the Georgia Forest Commission has developed an *Urban Model Forest Book* to provide communities with information to provide green infrastructure and a sustainable urban forest (Georgia Forestry Commission 2001). The concept of a 'model urban forest' is based on the need to

> *…re-examine the current development attitudes and place trees on the same level of importance as other critical infrastructure elements like roads and utility lines* (Georgia Forestry Commission 2001 p.6).

Table 6 summarizes how the 'existing development model' can be compared with the 'urban forest model'.

Table 6: Urban Forest Model

NOTE:
This table is included on page 22 of the print copy of the thesis held in the University of Adelaide Library.

Source: Georgia Forestry Commission (2001).

The Georgia Urban Forest Model aims to create space for trees through the use of three policy models that encourage preserving, and planting more tree canopy: a public education model; an ownership model; and a regulation model. These models will have different applications in: the urban core; older suburbs; recent suburbs; and rural areas (Georgia Forestry Commission 2001).

3.4 Streetscape design

Urban design

Trees are a significant element in the design of urban streetscapes (Jacobs 1993). Successful streetscape design, incorporating street trees, requires an effective collaboration between a range of disciplines, from the broad fields of design, engineering and science. According to Philip Craul

> *Landscape design is an interdisciplinary art and science. When the best of art is coupled with sound science and application of appropriate technology a successful design results. This goal can be accomplished through the mutual interaction of the landscape architect, scientist and engineer. Too often, lack of funds or failure to appreciate the interaction prevents designs from being successful* (Craul 1992 p.361).

From a design perspective, the two disciplines most involved in streetscape design, are landscape architecture and urban design. Landscape architecture is a formal discipline with its own professional institutes and accreditation procedures[5]. Landscape architecture is, itself, a multi-disciplinary field combining art and science to generate creative solutions for urban and natural environments. Urban design is not so much an accredited profession as a philosophical position and holistic approach to urban place-making[6].

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[5] In Australia the professional institution which gives accreditation to landscape architects is the Australian Institute of Landscape Architects (AILA) (http://www.aila.org.au). In the United States the professional body is the American Society of Landscape Architects (ASLA) (http://www.asla.org/).

[6] For an Australian perspective on urban design refer to the Urban Design Forum, a non-profit network promoting better design of Australian cities and towns (http://www.udf.org.au/). For a

> *Urban design is the art of making places for people. It is therefore concerned with how they function, not just how they look. It covers the connection between people and places, movement and urban form, nature and the built fabric and the processes for ensuring successful places are delivered and maintained* (Llewelyn-Davies 2008 p.12).

Streetscape design is one specific aspect of urban design that focuses on the planning and design of the different elements within the public street corridor, and in some cases the design of adjoining buildings and spaces. According to Davis,

> *…the scene, including all that we see in the street, is what we mean by streetscape. We do not only look at the buildings...we look at the whole scene including the spaces between buildings. This includes the quality of the pavement surfaces, the odd pieces of street furniture as well as the official traffic related street equipment* (Davis 1996 p.12).

Streetscape definitions

The street corridor itself comprises a number of zones and elements requiring definition at the outset. These vary between different traffic management authorities. Table 7 presents a typical set of definitions adopted by Landcom NSW (Landcom 2006).

Table 7: Streetscape terminology

NOTE:
This table is included on page 23 of the print copy of the thesis held in the University of Adelaide Library.

Source: Landcom (2006).

United Kingdom perspective refer to Llewelyn-Davies (2008). Urban Design Compendium 2, English Partnerships.

Road authorities also classify roads into hierarchies of road types which together form a local movement system. Road types such as arterials, collectors, local streets, and lanes and access-ways, vary in terms of design speeds and vehicle capacity, and in road reserve and carriageway width, influencing tree planting opportunities[7].

Within the street reserve, street trees have traditionally been planted in the verge between the footpath and carriageway. A detailed history of the street and of street trees is not presented here[8], however it is recognized that the verge existed before the advent of the motor vehicle and sealed roads, as a buffer between pedestrians and traffic on unpaved, muddy streets. Trees were later added to the verge by abutting property owners or local authorities (Miller 2007). Streets have long since been paved, but the verge has been retained for the aesthetic benefits of tree planting, and as a location for services, and in northern latitudes for snow storage and removal. The avenue, with trees planted in the verge on both sides of the street, has become the basic template of street tree planting. Lawrence traces the history of the avenue as a linear promenade in Europe, and in a less regimented form in the United States (Lawrence 1995). In the United States tree planting in the public verge by adjacent property owners is generally accepted in some areas as the only source of street trees, a practice discouraged in Australia (Miller 2007).

Street trees may also be planted next to the property boundary if the footpath is located adjacent to the kerb. In the United States, in narrow streets, or streets with overhead power lines, local authorities may also acquire voluntary easements over adjacent private property for tree planting purposes (Miller 2007). Street trees can also be planted in medians, parking lanes and footpath extensions, and even in containers where planting space is limited.

Streetscape design principles

Streetscape design strategies are often based on a set of 'design principles'[9]. For example Jacobs (1993) identifies the physical qualities required for 'great streets'. Street trees were seen to make a significant contribution to each of these qualities.

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[7] Refer to publications such as those by Landcom NSW for typical examples of model street types Landcom (2006). Street Design Guidelines. NSW, Landcom.

[8] Refer to publications by Henry Lawrence which trace the history of the avenues in the United States, Europe and elsewhere: Lawrence, H. W. (1995). Changing Forms and Persistent Values: Historical Perspective on the Urban Forest. Urban Forest Landscapes: Integrating Multidisciplinary Perspectives. G. A. Bradley. Seattle and London, University of Washington Press, Lawrence, H. W. (2006). City Trees. Charlottesville and London, University of Virginia Press.

[9] See for example Gehl, J. (2002). Public spaces and public life : City of Adelaide, 2002 Adelaide, S.A., Planning SA.

a) **Places for people to walk with some leisure**. Trees planted along a kerb, especially if closely spaced, define a pedestrian zone separated from vehicular traffic, creating a sense of safety both physically and psychologically. Trees planted in the parking lane may also help to bring it visually into the pedestrian realm.
b) **Physical comfort**. Street trees provide physical comfort for pedestrians by providing shelter from wind and rain in winter, and cooling shade in summer. Deciduous tree also provide access to warming sun in winter. Closely spaced trees can provide continuous shade and shelter in all seasons.
c) **Definition.** Street trees provide physical definition, vertically with 'walls' of tree trunks, and horizontally with 'roofs' of tree canopies. The most satisfactory proportions between street width and the height of its vertical edges have long been a concern of architects and city designers.
d) **Qualities that engage the eye**. Street trees add visual complexity to the streetscape, and have the special attribute of a constant sense of movement of leaves and branches, and changing patterns of shade and light. Green is also perceived as a restful colour in urban settings.
e) **Transparency**. Trees provide a semi-transparent edge to the street.
f) **Scale**. Trees can also provide a sense of human scale in the streetscape.
g) **Design unity**. Trees create a sense of design unity, especially with relatively close spacings and continuity of planting[10].
h) **Maintenance**. In the best streets, trees appear cared for, and adequate funds need to be allocated for their maintenance.

Streetscape design process

Streetscape design and construction, incorporating street trees, is a multi-disciplinary process. According to Thompson and Sorvig:

> *Like any form of complex activity, landscape-making benefits from collaborative efforts* (Thompson & Sorvig 2000 p.21).

The minimum team for a successful built landscape project comprises four roles: client; designer; builder and maintenance person (Thompson & Sorvig 2000). Project delivery is usually based on

[10] Jacobs recommends a spacing of 4.5 to 7.6 m, however wider spacings may be required to avoid canopy overlap and ensure tree health. Wide spacings and gaps make tree planting less effective in achieving design unity. Once a spacing of trees has started it should be continued and 'exceptions' avoided. Avoidance of tree planting at intersections, as required by traffic authorities to maintain sightlines, also detracts from the objective of design unity. Jacobs, A. B. (1993). *Great Streets*, Massachusetts Institute of Technology.

process involving the traditional steps of: design; documentation; construction; and operation/maintenance. Many authorities have formulated these four basic steps into detailed project delivery models[11]. The Australian Institute of Landscape Architects has published a *Scope of Services* outlining the various steps in the project delivery process (AILA 2004). The following section presents a typical streetscape design and delivery process based on the AILA model.

Stage 1-Project Pre-design. The first stage may involve project definition, preliminary feasibility studies, and the preparation of a landscape design brief. It may also involve the preparation of a wider Urban Design or Street Tree Master Plan. This stage will usually provide the rationale for incorporation trees in the design.

Stage 2-Project Design. This will usually include a site-analysis process, followed by the preparation of a schematic or concept design, which will include trees as conceptual design elements. This will be followed by more detailed design or design development which may include more detailed landscape plans, preliminary planting details and species selections. The purpose of this stage is to finalize all aspects of the scheme, including tree planting, in a realistic fashion, before proceeding to the preparation of the final documents.

Stage 3-Project Documentation. Project documentation involves the preparation of the final working drawings (with sufficient detail for construction purposes) and technical specifications (including specifications for the supply, installation and maintenance of plant material). It will also include the preparation of accurate budget estimates.

Stage 4-Project Implementation. Project implementation includes the Tendering phase (including the selection of landscape contractors), and the Construction phase (involving administration of the landscape contract).

Stage 5-Project Post-implementation.
Post-implementation tasks include administration of the specified establishment period for landscaping, followed by the on-going management and maintenance of the project by the client or their contractors.

The design process is essentially iterative in nature, with street tree proposals being continually negotiated with the competing requirements of traffic engineering, road safety, stormwater drainage

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[11] See for instance Main Roads (1998). Road Landscape Manual. Brisbane, Queensland Main Roads.

and above and below ground services. Street tree proposals will also be evaluated in terms of project budgets and community/stakeholder processes[12].

3.5 Conclusions

Streetscape design to accommodate trees requires a collaborative, multi-disciplinary approach combining the disciplines of science (arboriculture), art (urban/landscape design), and technology (engineering). Municipal arborists are the key agents of urban street tree planting and maintenance. In the past two decades the practice of arboriculture has evolved in two key ways: to a more scientific approach based on an improved understanding of tree biology; and a shift of focus from the planting and care of the individual tree, to the management of the urban forest. Other changes in arboricultural practice reflect changing community values, from tree planting primarily to enhance urban amenity, to a focus on risk avoidance and management. In the future the focus may be on an asset management approach to street trees. Another possible change is in the relationship between municipal arborists and works engineers, with the recognition of trees as green infrastructure.

Street tree planting today also operates within a 'triple bottom line' sustainability agenda. While much of the current sustainability focus is on the broad concept of 'sustainable development', the concept of sustainability has intrinsic meaning in the fields of ecological design and sustainable forestry practices. Sustainable landscape design is based on a set of principles that emphasize the concept of the sustainable management of resources including water, materials and energy. Sustainable urban forestry aims to manage urban tree populations over their life-cycle to maximize the public benefits they generate, while minimizing management costs and public risk.

Finally, street trees are a significant element in the creation of urban streetscapes. They need to be integrated with both functional engineering requirements, and with the urban 'place making' aims of landscape designers. Street corridors are configured to accommodate a range of functions, including different modes of traffic management, service locations and the creation of urban amenity. Trees are typically located within verge to create traditional avenues, but other locations are possible. Importantly, street trees contribute significantly to many of the principles underlying the design of streets as human places. These include spatial definition, human comfort, and aesthetics.

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[12] See for example PPK (2000). Upgrading of Portrush Road: Design Development Report. Adelaide, PPK Environment and Infrastructure Pty Ltd.

4 The role of street trees

4.1 Introduction

The following chapter provides a brief overview of the role of street trees in the city. This includes; the rationale for planting street trees, in terms of the net benefits they deliver to the city; the biological requirements that need to be met to grow healthy long lived trees in urban areas; and the nature of the hostile environment of the city, in which trees are expected to survive.

4.2 Street tree benefits

Street trees are a significant component of the urban forest, and deliver 'triple bottom line' (social, economic and environmental) benefits to the city (Johnson 2003). In the last decade extensive research has been undertaken documenting the benefits delivered by urban trees, as well as the wider benefits provided by urban nature and urban green-spaces, often in conjunction with the promotion of the concepts of urban forestry (McPherson 1995; McPherson 2005; Nowak & Dwyer 2007; Fam *et al.* 2008; Clark & Matheney 2009).

In the United States a number of institutions maintain research programs, as well as websites promoting the benefits of the urban forest. These include the International Society of Arboriculture (http://treesaregood.com), and the United States Forest Service (www.itreetools.org). In Australia the TREENET organization conducts annual Symposia in Adelaide, which address a range of urban tree issues, including street tree benefits (Moore 2000b). Other non-government organizations also promote urban trees and urban greening, and conduct seminars, featuring overseas tree experts, including the consulting arboricultural firm Treelogic in Victoria (www.treelogic.com.au), and the peak garden industry body, the Nursery and Garden Industry Association (NGIA) (www.ngia.com.au).

Studies of urban tree benefits tend to categorize them as either: social (including both human health and well being, and deeper spiritual and psychological significance); economic; or environmental (including ecological benefits) (Tarran 2006). The visual and aesthetic benefits of street trees are usually classified under social benefits, but appear to have received less attention in recent years with the focus on quantifying the measurable social, economic and environmental services provided by the urban forest. These somewhat 'intangible' benefits may be less well understood, and less easily measured by researchers from the biological or social sciences, with little research published by landscape architects and urban designers (McLean *et al.* 2007).

4.2.1 Environmental benefits

The environmental benefits of urban trees are of significance in terms of both improving the amenity of a street for its users, and also in terms of the wider sustainable development. A number of researchers have catalogued these environmental benefits (Nowak & Dwyer 2007). The most significant environmental benefit is probably the ameliorating effect of street trees on the urban climate and microclimate (McPherson & Rowntree 1993; McPherson 1994b). According to O'Brien,

> *Trees improve cities climatically, indeed this is probably the greatest benefit of tree planting in a built up area* (O'Brien 1993 p.14).

Trees can improve local microclimate, and reduce the 'urban heat island effect', where the air and surface temperatures of urban areas are much higher than those of surrounding rural or forest areas (McPherson 1994b; Rosenfeld *et al.* 1998). This is achieved by two major natural mechanisms: temperature reduction through shading of urban surfaces from solar radiation; and by evapotranspiration, which has a cooling and humidifying effect on the air (McPherson *et al.* 1988; McPherson 1994b; Pokorny 2001; Georgi & Zafiiridiadis 2006). In fact it has been suggested that trees can operate as natural 'air conditioners' which require little energy inputs to operate (Pokorny 2001). Humidity tends to be low in cities due to increased heat loads and the removal of rainfall as stormwater. Vegetative evapotranspiration increases humidity and levels of human physical comfort (O'Brien 1993).

It has been estimated that, in the United States, half of the energy consumed in air-conditioning occurs in areas which are 'urban heat islands' (Rosenfeld *et al.* 1998). Research has shown that appropriately planted trees can play a role in reducing building energy consumption, by reducing air temperatures, and by the direct shading of buildings (Heisler 1986; Simpson & McPherson 1996; Akbari *et al*. 2001; Coutts *et al.* 2007; Laband & Sophocleus 2009; Donovan & Butry 2009). Trees can also redirect winds or reduce wind speeds, reducing heat loss in winter (Heisler 1986). In the United States the potential energy savings of the urban forest have been quantified in a number of cities (McPherson *et al.* 1988; McPherson & Rowntree 1993; McPherson & Simpson 2003). However Dwyer et al. (1992) point out that such energy savings are only realized if trees are planted appropriately and that inappropriate tree placement can actually increase costs. Trees planted in parking lots provide one of the best opportunities to reduce urban heat island effects through the shading of bitumen surfaces and vehicles (Scott *et al.* 1999).

The second major environmental benefit of urban trees is that of improving air quality in cities. The natural functions of urban trees can: remove atmospheric pollutants; oxygenate the air; and absorb carbon dioxide through photosynthesis (Brack 2002; Nowak *et al.* 2006). The leaves of trees also collect and trap airborne particles on their surfaces. Oxygenation, however, is only of limited value compared to other oxygen sources such as the oceans and forests (Nowak *et al.* 2007). The most significant impacts on human health and environmental quality are through reductions in carbon dioxide and atmospheric pollutants (Nowak *et al.* 2002; Nowak *et al.* 2006; Nowak *et al.* 2007).

Urban trees are now being recognized for their potential role in carbon sequestration and storage, in the context of climate change (Ferrini & Nicolotti 2009). Moore estimates that the 100,000 public trees in Melbourne would sequester about one million tonnes of carbon (Moore 2006). The potential of urban trees for carbon storage, however, should not be overstated, as street trees are often short lived and small in stature (Nowak & Crane 2002; McPherson 2008). However, in terms of climate change, urban trees can play a significant 'buffering' role, particularly in terms of their potential to reduce the urban greenhouse effect. Reduced energy demand from reduced air-conditioning also lead to a reduction in carbon emissions from power stations (McPherson & Simpson 2001).

The role of street trees in the urban water cycle is also now being recognized (Bernatzky 1983; MacDonald 1996). Tree canopies intercept rainfall and modify stormwater runoff, reducing demands on urban stormwater infrastructure (Xiao *et al.* 1998; Xiao *et al.* 2000; Xiao 2002; Xiao *et al.* 2006). Tree root systems can also help reduce soil erosion by stormwater flows (Lull & Sopper 1969). Trees root systems can also play a role in the bioremediation of stormwater flows or contaminated soils, by nutrient uptake and pollutant removal (Hough 2004).

Street trees can also have ecological benefits in terms of enhancing biodiversity and creating urban wildlife habitats and corridors. However street tree plantings often comprise monocultures, lacking species diversity, limiting biodiversity and exposing street tree populations to the threat of species specific diseases (Richards 1993; Alvey 2006; Frank *et al.* 2006). Street tree plantings also do not usually include the creation of an understory habitat. Street tree plantings may also, for a variety of reasons, exhibit a preference for exotic cultivated species, rather than native or indigenous species (Moore 2003; Hough 2004). However it has been demonstrated that even exotic tree play some role in attracting wildlife (Tait *et al.* 2005; Young & Johnson 2005). Street trees are utilized by a variety of bird species, including native birds, especially those well adapted to the urban habitat (Tzilkowski *et al.* 1986; Fernandez-Juricic 2000).

Other environmental benefits include modified wind flows, reduced glare and noise reduction (O'Brien 1993). Street trees can act as porous windbreaks, reducing turbulence and wind-tunnel effects in cities. Street trees can also play an engineering role by reducing glare from buildings, and more importantly reducing driver dazzle from oncoming headlights. However urban trees provide only minor acoustic or noise reduction benefits, unless associated with earth mounding or noise-walls. Street trees however can also play an important psychological role by masking noise with their rustling leaves.

It is now widely accepted that human activities are contributing to global climate change due to increased levels of greenhouse gases in the atmosphere (Thom *et al.* 2009). The impacts of climate change are difficult to predict and vary from region to region, however the likely impacts in Australia include: increased temperatures; reduced rainfall and extended periods of drought; increased bushfire risks; and more extreme weather events such as storms and flooding (Suppiah *et al* 2006). Changing climatic regimes will impact on the health, structure and management of the urban forest (Moore 2006). The urban forest can also play a role in the two main responses to climate change, mitigation and adaptation. Urban trees can contribute to net reductions in atmospheric CO_2 through: carbon sequestration and storage; and avoided CO_2 emissions due to building energy savings. These reductions must be balanced against CO_2 released by the decomposition of dead trees and vegetable matter, and emissions produced in the management of the urban forest (McPherson 2009). Urban vegetation, however, is not included in calculations of greenhouse gas emissions for the purposes of creating carbon sinks to store carbon and reduce atmospheric CO_2 levels (Moore 2006). In the United States, however, the State of California has developed the *Urban Forest Greenhouse Gas Reporting Protocol,* an accounting and reporting tool that allows communities to obtain carbon credits for urban forest schemes (CCAR 2008a). To be eligible, schemes must meet a number of criteria such as a stable tree population and long term ownership. The protocol includes a registry and annual online reporting of Net CRT (carbon stored minus carbon emitted). A Centre For Urban Forest Research (CUFR) Tree Carbon Calculator has also been developed as part of the reporting protocol, a standardized Excel based carbon calculation tool, optimized for California's climatic zones (CCAR 2008b). The tool calculates carbon sequestered, carbon stored in dry biomass, and carbon emissions avoided by energy conservation.

There are number of issues associated with the role of the urban forest in climate change mitigation. These include the relatively minor levels of sequestration compared to urban greenhouse gas (GHG) emissions, the short life span of urban trees, and the high inputs involved in planting and management. The other role of the urban forest is in adaptation to unavoidable climate change (Thom *et al.* 2009). The urban forest can assist in reducing temperatures in cities through shading, evapotranspiration and wind speed modification (Akbari *et al.* 2001). Urban trees can also play a role in relation to future climate change impacts such as shelter from extreme weather events, and flood reduction (McPherson *et al* 2006). It should be noted, however, that conflicts may occur between adaptation and mitigation strategies. For example urban densification to achieve more compact, less car-reliant cities, may lead to a reduction in urban green spaces and urban trees (Hall 2008). Similarly the need for solar access to roof mounted photovoltaic cell panels may conflict with the objective of shading building roofs with tree canopies.

4.2.2 Social benefits

Recent research has also emphasized the social and psychological benefits of urban nature, urban greening and urban trees (Tarran 2006; Elmendorf 2008). This has focused on two main areas: benefits to human health and well-being; and the deeper psychological attachment of people to trees.

Human health and well being

In 1929 biologist E.O.Wilson used the term 'biophilia' to describe our subconscious attachment to the rest of life, and suggested this had its origins in human evolution (Wilson 1984). Tarran (2006) emphasizes the social and psychological benefits of urban trees. While there may be technological alternatives to providing the same environmental benefits as trees

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

Research over the last twenty years has investigated connections between urban nature and human health and well-being, with much of the research undertaken by practitioners in the social sciences. Research into the therapeutic and restorative effects of nature includes the work of Rachel and Stephen Kaplan into ways in which the natural environment can foster people's well-being and their ability to function effectively (Kaplan & Kaplan 1989; Kaplan 1995). Roger Ulrich (1981; 1984) examined the restorative effects of natural views on hospital patients. Similarly green settings were found to have positive effect on Attention Deficit Disorder (ADD) (Faber *et al.* 2001). In a related field, Kuo and Sullivan have shown that the presence of nature, including housing areas with trees, can enhance the physical and social health of individuals and communities, including reducing aggression and crime (Kuo & Sullivan 2001a; 2001b; Kuo 2003). The presence of vegetation, such as greenery and trees, has also been found to increase social interaction in urban neighborhoods (Kuo *et al.* 1998). This does not necessarily imply a direct cause and effect between urban nature and human behaviour, but rather a consequence of enhanced social interaction opportunities in urban green spaces (Elmendorf 2008).

Cultural values

Significant cultural meaning is attached to trees and forests, including archetype and myth (Dwyer *et al.* 1994; Konijnendijk 2008). Trees play a symbolic role in all of the world's major religions (Schama 1995). Dwyer *et al*. (1991 p.138) recommended adopting a broader perspective on urban trees

> *…one that takes into consideration the deep psychological ties between people and urban forests and trees.*

Research at the Morton Arboretum in Lisle, Illinois has identified a number of themes including: the sensory dimension of trees (Ulrich 1981); the symbolic value of trees, as symbols of people (Appleyard 1980) and as religious symbols (Chenoweth & Gobster 1990); and human roots in the forest (Appleton 1975; Appleton 1984). The act of tree planting has also been examined, as a demonstration of a commitment to the future and to environmental improvement. Because of their longevity, tree planting creates a legacy for future generations, and a link between generations (Moore 2000b).

Trees also have cultural and heritage values, as in the creation of ‘avenues of honour’ (Cockerell 2008). Communities may place high values on trees compared with other aspects of their urban surroundings, and develop significant attachments to local trees (Hull 1992). This is also reflected in reported preferences by residents for tree lined streets (Getz *et al.* 1982).

Historically trees have played a significant ‘place making’ role in cities defining a ‘sense of place’ when configured as an individual shade tree, avenue or grove (Moore *et al.* 1988). Trees continue to play a significant place making role in modern cities (Arnold 1980). According to Christopher Alexander in his book *A Pattern Language*

> *Trees have a very deep and crucial meaning to human beings. The significance of trees is archetypal; in our dreams they often stand for wholeness of personality. The trees people love create special places; places to be in and places to pass through. Trees have the potential to create various kinds of social spaces* (Alexander 1977 p.798).

Visual and aesthetic benefits

The visual and aesthetic benefits of street trees have received less attention in recent research, compared to the significant body of research on environmental, economic and human well-being benefits. In part this may be due to a shift in urban forestry away from an aesthetic rationale for street tree planting, to more pragmatic rationale based on quantifiable benefits more easily understood by municipal asset managers. In addition, there has not been a large amount of research in the topic undertaken by landscape architects and urban designers familiar with aesthetic principles, with most research being quantitative in nature and undertaken within the fields of arboriculture, environmental science, social science and economic modeling (McLean *et al.* 2007).

A number of landscape architecture and urban design texts refer to the role of trees in the design of urban spaces, including streets. Because of their size and longevity, trees are a major element in urban landscape design (Dwyer *et al.* 1994). Trees provide structure, connection, presence and scale, amelioration of harsh environments, and a capacity to link diverse landscapes (Moore 2000b). In her seminal 1961 book, *The Death and Life of Great American Cities*, Jane Jacobs noted the important role of street trees in creating visual unity in the modern city streetscape (Jacobs 1961). Alexander (1977) has noted the 'place making' role of trees in urban landscapes, as a single tree, grove of trees or a linear avenue. Arnold (1980) examined the role of trees in urban design in some detail, including street trees. O'Brien (1993) examined the aesthetic and planning contributions of street trees, comparing the cities of Birmingham and Munich. Based on a number of international case studies, Alan Jacobs has examined the qualities that contribute to 'great streets' (Jacobs 1993), and to boulevards (Jacobs *et al.* 2002).

Criteria for good streets identified by Jacobs included accessibility, comfort, safety and security, interest and activity, legibility, spatial definition, and visual quality (Jacobs 1993). The 'aesthetic' rationale for street trees, in fact, goes beyond simple visual appearance, but also includes the wider concept of urban amenity with its consideration of factors such as physical and psychological comfort, and functionality. Jacobs concluded that street trees are more than just 'aesthetic decoration', and are in fact one of the most important elements in the design of the urban streetscape.

> *Given a limited budget, the most effective expenditure to improve a street would probably be on trees. Assuming that trees are appropriate in the first place, and that someone will take care of them, trees can transform a street more easily than any other physical improvement. Moreover, for many people trees are the most important single characteristic of a good street* (Jacobs 1993 p.293).

O'Brien (1993 p.5-11) identifies a number of functional and aesthetic contributions to urban streetscapes. These include

a) Creating or reinforcing identity in a street.
b) Complementing historic or culturally significant buildings or streetscapes.
c) Enhancing pedestrian or vehicular orientation, legibility and way finding. Street trees can emphasize direction and directional change by accentuating road lines. They can emphasize a sense of movement, and their spacing can be manipulated to create a desired ambience, with closer spacings emphasizing a sense of speed. Trees can also be used to emphasize road junctions and focal points, and to reinforce the hierarchy of streets within the city.
d) Trees can play a symbolic or monumental role, for example in major boulevards and city gateways.
e) Enhancing visual amenity through screening unsightly views, softening the mass of large buildings, and reducing the apparent width of streets (especially if trees are planted adjacent to the kerb).
f) Providing visual interest, colour and a sense of movement in urban settings.
g) Providing awareness of seasonal change.

h) Providing a sense of human scale by creating smaller spaces within the wider streetscape, both vertically (by creating 'walls' of tree trunks), and horizontally (by creating 'roofs' of tree canopies).
i) Providing clear spatial definition in streets, for example by separating pedestrian and vehicular zones, both physically and psychologically.
j) Most significantly, street trees can provide a unifying element in an often visually diverse and sometimes chaotic urban streetscape. This design unity, however, is not 'boring', as it is coupled with a sense of variety, with each tree having its own individual character.

4.2.3 Economic benefits

Recent research has also focused on quantifying the economic benefits of both street trees and the urban forest. The amenity value of an individual tree can be expressed in monetary terms using a number of established formulas, with the Thyer and the Burnley methods being most commonly used in Australia (Moore 2000a).

Research by Kathleen Wolf and others has shown that street trees can enhance adjacent residential property values (Wolf 1998). Residential property values were shown to increase an average of 7% with matures trees (Wolf 2007). Street trees have also been shown to be of potential economic benefit to business centres, in terms of increased visitation and spending (Wolf 2003a; Wolf 2005). Consumers were willing to pay an extra 8% or more on goods and services in well landscaped commercial districts, especially those with good tree cover (Wolf 2004).

A number of studies have also attempted to quantify the economic benefits generated by an individual tree, or the collective value of environmental services delivered by an urban forest (Coder 1996; MacDonald 1996; Hewett 2002). A study at the University of Adelaide attempted to estimate the gross annual benefits from a typical street tree in Adelaide (Killicoat *et al.* 2002). A four year old tree was estimated to generate a gross annual benefit of $171 per tree, consisting of energy savings due to reduced air conditioning costs, air quality improvements, stormwater management, aesthetics and other benefits.

A 1996 study of stormwater management costs, showed that the urban forest provided stormwater management benefits valued at USD$15.4 million in Milwaukee, Wisconsin, and USD$122 million in Austin, Texas, by reducing the need for constructing additional retention, detention and treatment capacity (MacDonald 1996). Other environmental services provided by trees, which can be given a monetary market value, include carbon sequestration and air pollution mitigation. For example, a study by Nowak in Chicago found that trees removed 15 metric tons of carbon monoxide, 89 metric tons of nitrous oxide, 191 metric tons of ozone and 212 metric tons of particulate matter in one year, with a market value of USD$9.2 million savings on pollution controls (Nowak 1994a). Another study in Davis, California, showed that the city's 24,000 public street trees provided USD$1.2 million annually in net environmental and property value benefits (Maco & McPherson 2003). It was also shown that the benefit cost ratio was USD$3.81 for every USD$1.00 spent on tree planting and management in Davis. Another study showed cooling cost reductions of 20-50%, and heating cost reductions of 10-15% for residential allotments with trees (Heisler 1986).

Economic modeling is now being commonly used in the United States to quantify the economic benefits generated by urban forests (USDA Forest Service 2005). The United States Forest Service provides online tools allowing communities to estimate the net economic benefits generated by their urban forest (http://www.itreetools.org/).

i-Tree Streets is an adaptation of Street Tree Resource Assessment Tool for Urban Forest Managers, (STRATUM), developed by Ed McPherson and others at the USDA Forest Service Pacific South West Research Station (http://www.itreetools.org/street_trees/introduction_step1.shtm). STRATUM uses tree inventory data to quantify the annual economic value of environmental and aesthetic benefits: energy conservation, air quality improvement, CO_2 reduction, stormwater control, and property value increases.

i-Tree Eco is an adaptation of the Urban Forest Model Effects Model (UFORE) developed by David Nowak and others at the USDA Forest Service, Northeastern Research Station, based on his research from the Chicago Urban Forest Project (http://www.itreetools.org/urban_ecosystem/introduction_step1.shtm). UFORE (http://www.ufore.org/) is a computer model that can calculate urban forest ecosystem services and values based on field data inputs and available data sets from external sources (Maco 2009).

Such economic modeling has been applied in a number of United States cities including Davis California, Milwaukee, Minneapolis, Pittsburgh, Houston and New York (Maco & McPherson 2003; Anon. 2005). Since i-Tree was first introduced in 2006, there has been interest in applying the tools outside the United States, including Australia. As the i-Tree tools were developed for use in the United States, they require regional adaptation for Australian conditions. International i-Tree users are advised to use i-Tree Eco for urban forest assessment projects as i-Tree Streets, (STRATUM) is less adaptable for international applications (http://www.itreetools.org/eco/international.php).

As an example, Table 8 presents the findings from the application of the UFORE model in a 2008 study of the structure, function and value of the Milwaukee urban forest (USDA Forest Service 2008).

Table 8: Milwaukee: Urban Forest Effects and Values.

NOTE:
This table is included on page 37 of the print copy of the thesis held in the University of Adelaide Library.

Source: Compiled from data in USDA Forest Service (2008).

Similarly, the STRATUM model has been applied in a number of cities, for example Pittsburgh in April 2008, (Table 9) to evaluate the resource structure, function and value of the city's street tree population (Davey Resource Group 2008).

Table 9: Pittsburgh Municipal Forest Resource Analysis.

NOTE:
This table is included on page 37 of the print copy of the thesis held in the University of Adelaide Library.

Source: Compiled from data in Davey Resource Group (2008).

4.2.4 The case for large trees

Geiger advocates the case for growing large trees in cities (Geiger 2004). Large, mature trees are considered to deliver more significant benefits than smaller stature trees, therefore larger species of street trees should be planted, and allowed to grow to maturity to maximize their benefits. Large trees also comprise a significant investment in time and energy.

> *Given the relatively slow growth rates and high value of urban trees, substantial losses can be associated with changes that eliminate large trees. Furthermore, it may take decades for newly planted trees to become large enough to make substantial contributions. The important contributions of large trees include aesthetics, cleansing the air, retaining rainfall, providing shade, and providing symbolic heritage values. In fact it is the enduring nature of large trees in a rapidly changing urban environment that contributes to their high symbolic value and a sense of permanence in our fast changing society* (Dwyer *et al.* 2003 p.49)

Large trees provide improved shade, water quality and air quality (McPherson 2005). Research by David Nowak shows that large trees out-perform small trees in moderating air temperatures, blocking UV radiation, conserving energy, sequestering carbon and reducing air pollution, in a manner directly related to the size of the tree canopy (Nowak 2004). McPherson estimates that a large tree with a height of 14.3 m provides three times the annual environmental benefits of a similarly aged 6.7 m high tree, and that the value of benefits increases faster than the costs of managing a larger trees (McPherson *et al.* 2006)

Larger trees also have greater visual presence, and are often more highly valued by residents, especially where 'canopy closure' over the street is achieved (Kalmbach & Kielbaso 1979; Schroeder & Cannon 1983; Sommer *et al.* 1989; Schroeder & Ruffolo 1996; Schroeder *et al.* 2006; Heimlich *et al.* 2008). In one study the single largest factor in determining the attractiveness of a street scene was the size of the trees and their canopies (Schroeder & Ruffolo 1996).This was supported by a study in which there was a preference for large canopied trees in a tree replacement program (Heimlich *et al.* 2008). According to Schroeder *et al.* (2009)

> *Big trees have long been a significant feature in many cities and towns. A canopy of mature trees arching over the street and shading properties has defined the character of many urban and suburban communities* (Schroeder *et al.* p.60).

However, in the United States, surveys of tree planting practices from the 1970's to the 1990's found that many municipalities were deliberately planting more smaller trees, with larger trees progressively becoming a smaller component of urban tree populations. This has been driven, in part, by concerns of management costs and hazards. Some management costs such as pruning and leaf litter removal increase with tree size. Infrastructure conflicts also increase with tree size. And larger trees may be more prone to public risk from structural or root damage (Schroeder *et al.* 2009).Young and Johnson (2005) however note that a street with a small population of widely spaced large trees, will be more economical to manage than the same street planted with a larger number of more closely spaced smaller stature trees. Similarly a recent urban tree survey in England warned that replacing large native species with small ornamental cultivars, is leading to a significant reduction in environmental and aesthetic benefits (Britt & Johnston 2008).

With smaller allotment sizes, larger buildings and narrower streets in recent urban developments, available space for large tree planting is decreasing (Hall 2008). Service authorities and engineers also emphasize planting of smaller tree species, as the solution to conflicts with buildings, services or people. Tree professionals may also recommend planting the ‘right tree for the right place’. Sound decision making should balance the benefits of large trees against these cost (Schroeder *et al.* 2009). There are also opportunities to develop innovative solutions which better accommodate large trees in smaller spaces, such as those presented by Michael Kuhns, which include innovative below ground designs and directional pruning (Kuhns *et al.* 1985; Kuhns 2006; 2007).

4.2.5 Green infrastructure

Infrastructure systems are an essential part of the modern high density city. ‘Grey infrastructure’ comprises the engineered network of roads and services delivering specific services to the population of the city. Infrastructure systems require major capital investment to build and maintain, and are generally single use occupiers of often large areas of land (Wolf 2003).

‘Green infrastructure’ is an emerging concept, based on the realization that natural systems, including trees and urban forests, can deliver a range of engineering and human services to the city, known as ‘ecosystem services’ (Bolund & Hunhammar 1999). The concept originated in the United States in the 1990’s, emphasizing the ‘life support’ functions provided by the natural environment. Green infrastructure can provide quantifiable environmental services, including stormwater management , air quality improvement, carbon sequestration, and mitigation of the urban heat island effect (TCPA 2004). The concept also includes more anthropocentric functions of the natural environment, including recreational and cultural values (Bolund & Hunhammar 1999). The work of researchers such as Nowak and McPherson has demonstrated the range of ecological services that can be provided by the urban forest (McPherson 2005; Nowak & Dwyer 2007). Street trees can provide such services, as well as more specific engineering benefits such as extended road pavement life through shading, and their role as ‘traffic calming’ devices in city streets. Importantly, street trees can deliver multiple benefits from the valuable street space they occupy, as opposed to single purpose engineering infrastructure (Wolf 2003).

Table 10 presents a summary of the key ecosystem services that can be provided by urban trees.

Table 10: Summary of ecosystem services delivered by urban trees

Global climate modification	**Water cycle modification**
Carbon sequestration and storage	Flood reduction
Avoided CO2 emissions	Canopy interception and storage
Building energy savings	Increased soil infiltration (roots)
Local climate modification	Increased soil water holding capacity-ET
Temperature reduction	Improved water quality
Shading	Biofiltration
Buildings	**Soil improvements**
Urban surfaces	Soil stabilization
Evapo-transpiration	Waste decomposition
Wind speed modification	Nutrient cycling
Air quality improvement	**Biodiversity**
Pollutant removal	Habitat
Absorb gaseous pollutantsO3,NO2	Corridors
Intercept particulate matter PM10	**Human health and well-being**
Reduce air temperatures O3	Physical
Release O2	Social, psychological
Avoided pollutant emissions	
Source: Various sources in the literature	

As an example, McPherson (2004a) estimated the value of benefits generated from tree planting in Chigago, based on the range of ecological services provided by trees. A computer model was developed to estimate a thirty-year stream of benefits associated with planting 95,000 trees in streets, public spaces and private land. The projected present value benefits for planting 50,000 trees in Chicago are presented in Table 11.

Table 11: Projected present value of benefits for tree planting in Chicago (30 year analysis)

NOTE:
This table is included on page 41 of the print copy of the thesis held in the University of Adelaide Library.

Source: McPherson (2004a) p.127.

4.2.6 Street tree costs

To understand the net benefits delivered by street trees it is also necessary to consider the costs of planting, establishing, maintaining and eventually replacing a tree (Miller 2007). McPherson (1994a) analyzed in detail the costs and economic benefits of tree planting programs in Chicago over a projected thirty year period. Annual street tree cost items include tree purchase, planting, pruning, removal, pest control, tree-damaged infrastructure repair and replacement, leaf clean up, public liability costs and program administration (Young & Johnson 2005). Such costs vary from city to city. The cost estimates used by McPherson in the 1994 cost/benefit study in Chicago are presented in Table 12.

Table 12: Estimated street tree planting and management costs, Chicago 1994.

Source: McPherson (2004a) p.118.

More recent studies of the cost-benefits of street trees in United States by the Davey Resource Group (2008) have identified the annual street tree expenditures in a number of communities, as shown in Table 13.

Table 13: Comparison of annual street tree expenditures of five US communities

Source: Davey Resource Group (2008) p.17

Trees can be a source of real or perceived nuisance and hazard to the community, and a source of public liability claims against tree management authority by pedestrians, vehicle users and adjacent property owners (Heath 2002; LGA 2005). Significantly, street trees are often in a state of conflict with surrounding urban infrastructure, both above and below ground, including pavements, services and buildings (Wong *et al.* 1988; Hauer, Miller & Ouimet 1994; McPherson 2000; Rajani 2002). The annual cost of maintaining the urban forest will depend on the number of trees and species mix. Research in South Australia indicates that, based on annualized lifetime maintenance costs, there is an economic case for preferring large, long-lived tree species over shorter lived small-canopy trees planted at closer spacings (Young & Johnson 2005). Annual maintenance costs tend to be higher during the establishment period, decline as the tree matures, then increase as the tree reaches maturity and senesces, implying that trees should be removed and replaced before management costs exceed the benefits generated by the tree (Hitchmough 1994). Street tree issues can often be seen as a consequence of inappropriate species selection, leading to the search for the 'ideal street tree' and a preference for reliable and proven species such as the Oriental plane (*Platanus* x *acerifolia*) (Hough 2004). Tree management authorities may utilize tree species selection models that site factors and social and economic selection criteria (Hitchmough 1994; Miller 2007).

4.2.7 Conclusions

Street trees provide wide range of social, economic and environmental benefits to the city. Street trees can, in fact, be seen as a form of 'green infrastructure' delivering a range of ecological services. It is also evident that large, long-lived trees maximize these benefits. Street trees, therefore are more than just 'aesthetic decoration' but rather a valued and integral part of cities and should be allowed to survive and grow to maturity to deliver their benefits.

5 The needs of street trees

5.1 Introduction

The following chapter provides an overview of the biological needs of urban trees, including their key biological processes and the requirements to sustain those processes. The role of urban trees in a number of natural cycles is also discussed. Particular attention is given to conditions below ground, and to the interactions of tree roots, soil and water. The hostile nature of the urban environment in which street trees must survive is discussed, and its impacts on tree health and longevity. Particular attention is also given to the nature of urban soils, and the impacts of degraded soils, especially compaction, on urban trees.

5.2 Biological requirements

The benefits delivered by street trees are maximized by large, mature trees. Street trees, therefore, should be allowed to live and grow to maturity (Geiger 2003). However, too often professionals, even landscape architects, are unaware of the biological requirements of trees, selecting trees primarily for their attractive appearance (Urban *et al*. 1989). In 1996 United States landscape architect James Urban wrote

> *Time and time again landscape architects arrive at design decisions that ignore the basic biology of trees, making it difficult or even impossible for them to survive. As a profession we have given short shrift to the horticultural aspects of our knowledge base, reducing the time we spend studying horticultural principles and soils at a time when the pressure of urban development are making it more difficult to grow trees in our cities. The result is the average life expectancy of urban trees: a mere ten to fifteen years* (Urban 1996 p.77).

The following sections provide a brief overview of the biological needs of urban trees, from a design perspective. More detailed discussions are available in a range of arboricultural or biological texts (Craul 1992; Harris *et al.* 2004; Campbell *et al.* 2006).

Trees have the same biological requirements in the city as they do in the forest. In biological terms, there is no such thing as a 'street tree', only trees grown in streets. According to Simpson

> *There is no such thing known as a 'street tree' existing in nature. The term 'street tree' is a misnomer as trees are the products of a natural environment whereas streets form part of a built environment. It is the human love of trees that has brought trees from the rural to the urban environment* (Simpson 1981 p.57).

5.2.1 Natural processes

The three basic natural processes of photosynthesis, respiration and transpiration must continue to be sustained in the city, as they are in the forest (Harris *et al.* 2004). Table 14 summarizes the key environmental factors influencing each process.

Table 14: Environmental limiting factors on trees

NOTE:
This table is included on page 45 of the print copy of the thesis held in the University of Adelaide Library.

Source: Abridged from Harris, Clark and Matheney (2004).

5.2.2 Biological requirements

Trowbridge and Bassuk (2004) identify six basic requirements for growth: oxygen; carbon dioxide; light; water; nutrients; and appropriate temperatures (Trowbridge & Bassuk 2004). Above ground, carbon dioxide and sunlight are required for photosynthesis. Below ground, tree roots mine the soil for water and nutrients. Oxygen is required for respiration, in all parts of the plant, including those below ground. Appropriate temperatures are also required to sustain growth, both above and below ground. To these six requirements may be added the need for adequate soil volumes to support the plant, and provide the resources necessary for growth (Craul & Craul 2006).

Plant growth (in relation to crops) can also be usefully conceptualized in terms of interactions between defining factors, limiting factors and reducing factors. Defining factors determine potential maximum growth rate and include biological plant characteristics, and environmental variables such as atmospheric CO_2 concentrations, incoming solar radiation and soil and air temperatures. Factors which may limit growth include the availability of water and nutrients in the soil. If these are lacking the plant will not grow at its potential rate. Growth may then be further reduced by factors such as weeds, pests, diseases and pollutants (Eamus *et al.* 2006). In urban situations all of these factors may be affected.

Knowledge of these requirements is not new. As Cox stated in 1916 (Craul 1992 p.1).

> *The problems which have to do with soil, conditions are less simple of solution and yet it is upon the skill shown in solving them that the success or failure of the whole operation must depend. To secure correct soil conditions it is necessary to provide for each and every tree as follows:*
> *1. A sufficient amount of good soil*
> *2. Sufficient moisture*
> *3. Proper drainage*

4. Proper aeration of the soil
5. A supply of plant food

The situation today has not really changed, as we are still concerned with providing the same factors, but we still do not fully appreciate the conditions presented in the modern urban environment (Craul 1992).

5.2.3 Growth constraints

The efficiency of a tree's biological processes, and therefore its growth and life-span, will suffer if these essential requirements are not met in the urban environment (Mish 1986). Conditions below-ground are frequently ignored as they are 'out of sight, out of mind'. The initial causes of tree failure and death may also be difficult to determine, as a tree in an unhealthy state (for example due to deficiencies in water supply or nutrients) will be susceptible to invasion by pests or pathogens, that would be resisted by a healthy tree in the natural forest (Matheney & Clark 1998). Trees, like other organisms, have a genetic apparatus that determines their traits, including longevity. The extent to which these traits are expressed will depend on the tree's environment, and a tree with optimum conditions of light, water, nutrients, appropriate temperatures, oxygen and carbon dioxide is most likely to grow to its full genetic potential (Harris *et al.* 2004). The following section summarizes some of the key constraints within the urban environment (Simpson 1981; Mish 1986; Craul 1992; Trowbridge & Bassuk 2004).

a) **Oxygen**. With impaired drainage, soil pores may fill with water, making oxygen unavailable to the roots.
b) **Carbon dioxide**. Plants under stress close their stomata to reduce water loss. Low light levels also close stomata. As a result carbon dioxide is prevented from entering the leaf.
c) **Light**. Being the tallest plants in the forest, trees generally require full sun, which may be limited in urban environments with tall by buildings.
d) **Water**. In urban environments, with extensive impervious surfaces, trees may receive either too little water, or too much with inadequate drainage.
e) **Nutrients**. In urban environments soil pH can be extensively modified, making nutrients less soluble and therefore less available for uptake by the plant's root system.
f) **Appropriate temperatures**. Urban areas are characterized as 'heat islands' with temperatures elevated above the surrounding rural areas. In addition heat reflected or re-radiated from buildings and pavements causes accelerated water loss, and foliage or trunk damage in extreme conditions. Root-zone temperatures are also modified in the urban microclimate. Roots have generally evolved from growth in large soil masses buffered from daily temperature fluctuations, but in smaller soil masses in urban areas may be subject to damaging temperature extremes.

As discussed in a following section, two major factors influencing the ability of a tree to meet these requirements in urban areas are: soil compaction; and the extent of paved impervious surfaces.

5.2.4 Natural cycles

Consideration also needs to be given to the role of urban trees in the natural cycles which process water, carbon, nitrogen and minerals through the living and non-living worlds, and between the land, oceans and atmosphere (Campbell *et al.* 2006; Cross & Spencer 2009). A sustainable approach to design should attempt to integrate these natural cycles into the urban environment.

The hydrological cycle recycles and purifies water. It includes seven main processes: evaporation; transpiration (water lost from plants, having been taken up by their roots); condensation; precipitation; infiltration (water movement into the soil); percolation (water movement through the soil into groundwater); and runoff. The water cycle is driven by energy and gravity, however plants play a crucial role in terms of modifying rainfall inflows, water movement into and through the soil, and water outflows through evapotranspiration, surface runoff and subsurface drainage (Xiao *et al.* 2006; Cross & Spencer 2009). Table 15 provides a useful conceptualization of water flows in an urban landscape, in terms of inflows, storage and outflows. The key aim of Water Sensitive Urban Design (WSUD) is to better integrate the natural water cycle into the urban environment, at a range of scales (Argue 2004).

Table 15: Water flows in an urban landscape

NOTE:
This table is included on page 47 of the print copy of the thesis held in the University of Adelaide Library.

Source: Cross & Spencer (2009) p.89.

Plants play a critical role in the carbon cycle, photosynthesizing organic carbon compounds from atmospheric carbon, water and energy from sunlight, and by releasing oxygen during the same process. Plants are consumed by animals and the organic compounds are re-synthesized in other forms. Plants and animals release carbon dioxide into the atmosphere during respiration by oxidizing these organic compounds. The carbon cycle is completed as plants and animals produce waste products and die, with dead organic matter being decomposed, releasing carbon as carbon dioxide. Carbon is stored in trees and forests and can act as carbon sinks as long as they are actively growing, and reach a steady state as carbon dioxide uptake is matched by carbon dioxide released from death and decay (Nowak *et al.* 2007).

In the nitrogen cycle, small amounts of N^2 are converted into forms that can be used by plants, primarily by nitrogen fixing bacteria in the root nodules of some plants (Craul 1992). Decomposition of organic wastes releases nitrogen in the form of ammonia. Under aerobic conditions it is oxidized by nitrifiers to a nitrate. Plants usually take up nitrogen in the form of a nitrate in order to synthesize proteins. Humans also add nitrogen to the system through the use of nitrogen fertilizers, and disposal of wastewater into waterways.

These natural cycles may be highly modified in urban environments; in particular the presence of extensive paved and impervious surfaces tends to limit the natural cycling of water, carbon and nutrients.

5.3 Tree roots, soils and water

> *The largest impacts trees face in the urban environment are those that occur below ground…the ability of the root system to cope with hostile environmental conditions below ground, will often determine whether the tree flourishes, survives or fails…On the other hand, the development and function of tree root systems can impact on buildings, structures and pavements, both directly and indirectly… A better understanding of such interactions requires a sound knowledge of the basic properties of roots and root systems, including their form and function* (Roberts *et al.* 2006 p.40).

5.3.1 Root systems

The basic functions of a tree's root system are: uptake of water; uptake of mineral nutrients; transport of water and nutrients to the stem and support and anchorage for the tree. Roots also perform other functions including: supply of hormones to the shoots; storage of materials for tree growth; and the formation of symbiotic relationships with soil fungi (Roberts *et al.* 2006). According to Perry (1982) roots are as important to photosynthesis as leaves, through their supply of the necessary water and nutrients required in the process.

Trees also need large amounts of water to meet the daily transpiration and other needs such as cell turgor (Kozlowski 1985). This may amount to four times the weight of the plant. Most of this is absorbed through the root system, and the soil must be able to provide this water when required, and over the period between precipitation events.

However, despite their importance

> *Roots suffer from discrimination by being covered up, their nature and importance poorly understood by those who should know better and many times placed in an environment unfit for them. Many planning failures may be attributed to our ignorance of the normal course of root development and the influences of environmental conditions on it* (Craul 1992 p.122).

Our knowledge of tree root biology and root-soil-water interactions, in urban situations, has expanded dramatically over the past two decades, and has seen the passing of the 'out of sight, out of mind' era in arboricultural practice (Moore 2001). Landmark events included the three *Workshops on Tree Root Development in Urban Soils*, organized by the International Society of Arboriculture in 1994, 1998, and 2008 (Watson & Neely 1994; Neely & Watson 1998, Watson *et al.* 2009). Key publications related to tree roots include (Perry 1982; Craul 1985; Craul & Patterson 2002; Jim 2003; Harris *et al.* 2004; Roberts *et al.* 2006).

The old view of tree root systems, often illustrated in inaccurate diagrams, was of a compact root ball confined to the tree canopy drip line, with a deep vertical tap-root. This model has been superseded by advances in scientific knowledge, one of the most influential being that of Perry, who proposed the following revised view in *The Ecology of Tree Roots and Practical Significance Thereof* (Perry 1982 p.197).

a) Roots may spread 2-3 times the height of the tree, well beyond the canopy periphery (Watson & Himelick 1982; Gilman 1989).
b) The bulk of root growth is lateral, parallel to the soil surface.
c) On medium textured soils the bulk of the root system is in the top 1.0-1.5 m of soil, with most in the top 600 mm. Some roots may be found at greater depth, but these represent a small fraction of total root mass. Greater rooting depth may occur in conditions of enhanced soil oxygenation or decreased penetrative resistance.
d) The major structural roots (scaffold roots) grow horizontally from the tree base. Roots found at depth are known as sinkers (synonymous with vertical or descending roots) which grow down vertically from scaffold roots. Roots also grow upwards from the scaffold roots forming mats at or below the surface.
e) Tap roots are significant in seedlings, but do not persist in transplanted trees and lose their dominance to the developing scaffold roots. Tap roots are often a juvenile characteristic of trees, but only a small number of species have a tap root that persists into adulthood as a major woody root (Sutton 1980).
f) The soil environment is probably as important, or more so than the genotype in determining tree rooting patterns, in particular depth.

g) Tree roots do not grow 'towards' anything in particular, but are opportunistic and will flourish where conditions are favorable. Roots do however tend to grow along water, oxygen and nutrient gradients. Favorable conditions vary but include: bulk density less than 1.5 Mg m^3 (Craul 1985); soil penetrative resistance less than 0.2-0.3 MPa (Zisa *et al.* 1980); soil oxygen levels equal or greater than 13% of soil pore atmosphere; and adequate soil moisture between 0.03-0.3 MPa (Hitchmough 1994).

In summary, the root envelope of a tree, in an unconfined planting situation, will generally comprise a shallow 'root plate' or disk rather than a 'root ball'. A tree and its root plate has recently been conceptualized as resembling a 'wine glass on a saucer' (Urban 2008 p.85). Figure 1 illustrates the modern concept of a tree's root system.

NOTE:
This figure is included on page 50 of the print copy of the thesis held in the University of Adelaide Library.

Figure 1: Modern view of a tree root system

Source: Harris, Clark and Matheney (2004) p.27.

Root depth and spread

A popular misconception is that tree roots occur at significant depths in the soil profile. Numerous studies, involving root excavation, and data from wind-thrown trees, have shown that typically as much as 90% of tree root length occurs in the top metre of soil (Roberts 1976; Himelick 1986; Gasson & Cutler 1990; Dobson & Moffat 1993). Variation does occur for different vegetation types, and in terms of proportion of the root system concentrated in the uppermost soil horizon (Roberts *et al.* 2006).

> *This fact may not be realized by a large number of people who believe that trees have deep root systems and incorrectly conclude that shallow roots are not important to the vigor of the tree* (Craul 1992 p.137).

The roots of trees, and other plants, predominate in the upper soil layers for a number of reasons. Root systems acquire most nutrients in the surface horizons where decaying organic matter occurs. Deeper soils also tend to be a more difficult environment to exploit. Soil bulk density tends to increase with depth and non-capillary pore space declines, resulting in: mechanical impedance to root extension; and limited diffusion of oxygen necessary for root growth (Roberts *et al.* 2006).

Deep roots also play only a small part in tree stability. Resistance to wind-throw is mainly from the large roots close to the base of the tree, rather than very distant or deep roots (Mattheck & Breloer 1994; Wood 1995).

Deeper rooting may only be necessary where the tree needs to access water resources in periods of irregular supply. There are, in fact, examples where roots have been found at greater depths in deep loose soils (Perry 1982; Gilman 1990), and in areas of limited rainfall (Stone & Kalisz 1991). In Australia there are examples of very deep rooting *Eucalyptus marginata* trees in deep channels of low bulk density soils (Dell *et al.* 1983). Handrek (2008) reports that shrubs and trees adapted to seasonal drought can have roots that extract water from 10-12 m deep, and that the Spinifex grass (*Trioda* spp.) of arid Australia can send down roots 50 m. In the deep sands of arid south-western Western Australia, plants rapidly send down roots to 20 m to access water tables 10-20 m below the surface.

There has been considerable research into rooting depth in forest trees, due to the need to ensure adequate water and nutrient supplies (Stone & Kalisz 1991; Canadell *et al.* 1996). There has been less research into the lateral extent of individual root systems, considered to be of less importance in managing trees in the forest setting. Lateral extent however is of considerable importance in the built environment. Conceptions of lateral root extension have been influenced by circumstantial implication of trees in building damage (Cutler & Richardson 1989). It is clear that tree roots extend well beyond the canopy perimeter or drip line (Hodgkins & Nichols 1977). It is also clear that there is considerable variation between species (Gilman 1989; 1990). Gilman found a good relationship between crown spread and root radius, but the relationship tends to be species specific (Gilman 1989). In urban situations it has been found that the root radius is regularly equal to, or greater than, tree height (Cutler & Richardson 1989 Jim 2003).

Urban root morphology

The morphology or architecture of root systems is dependent on tree species (Toumey 1929). However root systems exhibit considerable flexibility and their form can be extensively modified by soil conditions (Roberts *et al.* 2006). Attempts to classify root systems according to species have been frustrated by the considerable range within species, and the strong influence of soils (Dobson & Moffat 1993). The actual root architecture of most species, however, is largely unknown, and is mostly based on North American, and to a lesser extent European observations (Hitchmough 1994). Scientific study of mature deciduous trees in Australia is limited (Sands & Misra 1991). Much less research has been undertaken into the more xeophophytic broad leaved Australian tree species. Hitchmough argues that, intuitively it may be thought that these trees would develop deeper root systems to survive severe drought stress (Hitchmough 1994).

The root envelope of a tree, in an unconfined planting situation, will generally comprise a shallow, circular 'root plate' or disk extending well beyond the tree canopy (Urban 2008). However, in congested urban situations this idealized shape will often be severely modified. In urban streets the accessible soil volume may be confined to an elongated corridor surrounded by building footings, compacted road base and below ground services, which is highly asymmetrical and vulnerable to damage (Jim 2003). In urban situations it has been found that the root radius is regularly equal to, or greater than, tree height (Cutler & Richardson 1989). Root systems will exploit channels of less dense, well oxygenated soils in hostile urban sites, and root extension may be in the form of wedges of favorable soil (Hodgkins & Nichols 1977; Cutler & Richardson 1989). Hitchmough (1994) estimates that these may extend: 4-6 m for a 4 m tall tree; 8-12 m for an 8 m tall tree; 16-24 m for a 16 m tall tree; and 24-36 m for a 24 m tall tree.

Craul (1992) also discusses the compartmentalization of rooting volumes available to urban trees, due to subsurface barriers. Containment can impact on root-shoot ratios, nutrient and water absorption, and mechanical support. Roots that extend outside the tree pit will conform to the available space resulting in unusual root forms. With trees planted between the kerb and footpath, roots are confined between the two structures, or grow under the footpath, developing a linear form. According to Craul (1992) roots do not tend to grow below the road surface, as evidenced in a severe storm in Washington D.C. in 1989 where most trees fell perpendicular to the kerb.

5.3.2 Soils and water

The desirable properties of soils vary between different disciplines. For horticultural purposes, a soil can be conceptualized as a porous matrix of mineral particles of various sizes, which form the skeleton of the soil. Horticulturists speak of an 'idealized' soil, in which these mineral particles comprise about 45% of the soil volume, with about 5% comprising organic matter, and with the remaining 50% comprising void space filled with either air or water, depending on the moisture status of the soil. In an idealized soil, with good horticultural properties, soil air and water will be equally divided. The properties of the mineral particles, and the relative proportions of the four main components, influences the soil's ability to support plant growth (Craul 1992). Figure 2 compares the typical properties of 'idealized' and compacted soils.

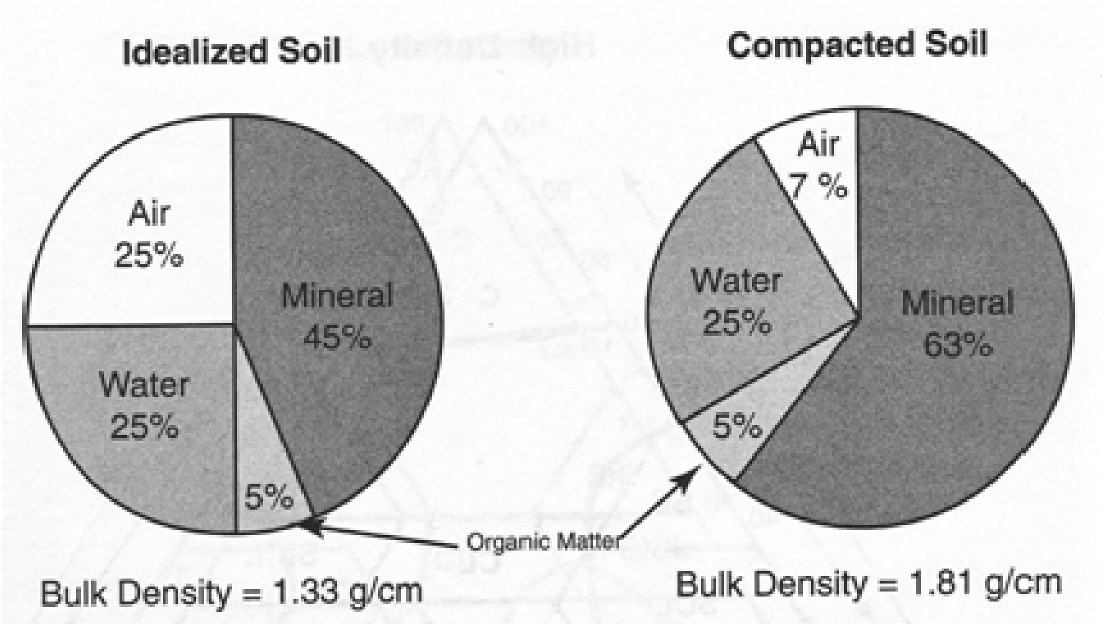

Figure 2: Idealized and compacted soils

Source: Craul & Craul (2006) p.160.

The geometric properties of the mineral matrix can be described in terms of: soil texture; and soil structure (Craul 1992; Roberts *et al.* 2006). Soil texture refers to the relative proportion of particles of different size classes. Soil structure refers to the arrangement of these particles into geometric patterns, in which particles are aggregated into larger units called peds. These two properties determine the amount of pore (void) space in the soil volume, and its distribution throughout the soil. Two main types of pores can be identified: small pores within the porous fabric of the individual ped, known as micropores; and the larger pores between individual peds, known as macropores. The porosity of the soil can be measured as bulk density, defined as the (oven dried) weight of a unit volume of dry soil, including the pore space volume. Soil structure is also important as most liquid and gaseous movement, as well as root extension, occurs in the larger macropores (Craul 1992).

Most trees grow best in well-aggregated, well drained soils with a bulk density less than 1.5 (Craul 1985). The normal growing range for clay soils is about 1.0-1.6, with root restrictions occurring above 1.4. The normal range for sandy soils is about 1.2-1.8, with root restrictions above 1.6. However many compacted urban soils have a bulk density of 1.6-2.0 (Rivenshield & Bassuck 2007). Table 16 presents Craul's summary of bulk density limits.

Table 16: Soil bulk density limits

Situation	Bulk density (Mg/m^3)
Forest soil (organic horizon)	0.2
Idealized soil(50% solid particles)	1.33
Limit to root extension-clays	1.55
Limit to root extension-sands	1.75
Well packed sand	1.8
Source: Compiled from Craul (1992).	

The ideal pore space for growing trees is around 50%. Patterson found that soils in the Mall in Washington D.C. were as compacted as brick, with pore space often less than 35%, and in some cases as low as 13% (Urban *et al.* 1989)

The capacity of a soil to store water is also a significant factor in tree growth. Trees require large amounts of water for transpiration, which must come from the soil. The soil must be able to supply this water when required by the tree. The soil must also be able to store sufficient quantities of water to carry the tree through dry periods. In addition, soil water is involved in the exchange and transport of nutrients and soluble salts (Brady & Weil 1999). Field capacity is a property of soil which influences plant-soil-water relationships. Soil is at saturation when all pores are filled with water. As the soil drains the largest pores empty first until no more water moves under gravity. At this point the soil is at 'field capacity', where the retentive forces exerted by the soil equal the gravitational force. The forces exerted by the roots then continue to extract water held in the soil pore spaces. At a certain stage the 'wilting point' will be reached, when water still remains in the smallest pores, but which cannot be accessed by the plant, as the forces holding the water in the pores exceeds that exerted by the roots. The difference between moisture content at field capacity and wilting point is termed available water. Soil texture influences field capacity, wilting point and available water. For example a sand holds only 4-5% available water, a silt loam about 24% (Craul 1992). Table 17 summarizes the water holding capacity of a range of soil texture types.

Table 17: Approximate amounts of water held in soils of different textures

NOTE:
This table is included on page 54 of the print copy of the thesis held in the University of Adelaide Library.

Source: Handreck (2008) p.51.

Craul cites Blume's (1986) description of the characteristics of a 'good' soil (Craul 1992 p.88).

a) *Deep rooting and ease of root penetration due to its high degree of aggregation and the presence of many macropores;*
b) *Sufficient water because of a large water holding capacity, especially under humid temperate conditions;*
c) *Optimal gaseous diffusion due to a high degree of aggregation;*
d) *Adequate amounts of nutrients in available and reserve form and in the proper ratio coupled with a large cation-exchange capacity, and;*
e) *A rich soil microflora and fauna that decompose organic matter rapidly, bring about nutrient transformations into available form, and provide a highly developed soil structure.*

5.3.3 Root growth limiting factors

Soil conditions of impedance (bulk density), moisture, aeration and temperature can influence root growth (Hopkins & Patrick 1969). Coder (2000) provides a simplified list of root growth resource requirements.

Table 18: Brief list of root growth resource requirements

NOTE:
This table is included on page 55 of the print copy of the thesis held in the University of Adelaide Library.

Source: Coder (2000).

Root extension occurs with the root tip pushing through the soil pore space. There is a minimum diameter pore that roots can penetrate, suggested to be 0.01 mm (Craul 1992). Roots tend to follow the line of least resistance, favoring the larger interpedal pores. In soft soils the roots may push aside the soil material. Roots can therefore extend with ease in well aggregated soils with continuous channels, as long as pore diameter exceeds root cap diameter. Soil strength is a measure of the resistance to this movement in the soil, and is primarily determined by soil texture, with finer textured soils having greater strength (Craul 1992).

Compacted soils tend to have smaller pore diameters and less favorable arrangement of pores, inhibiting root elongation. Root penetration can be related to soil bulk density. Root penetration is inhibited in fine textured soils at bulk densities of about 1.55 and 1.75 in sandy soils (Veihmeyer &

Hendrickson 1948). Roots can penetrate clay soils with bulk density of 0.9-1.3, and loamy soils with bulk density of 1.0-1.8 (Graecen *et al.* 1969). Trees can become 'pit-bound' if planted in tree pits dug in compacted soils, and the roots cannot elongate from the backfill of the tree pit into the surrounding compacted soil, if compacted to around 1.75 bulk density (Craul 1992). Mechanical impedance is also influenced by soil moisture. Any reduction in root elongation can have detrimental effects on overall tree growth (Krizek & Dubik 1987). Smith *et al* (2001a) tested the effects of commonly encountered levels of soil compaction found in urban soils on the root growth of four Australian native tree species. In moist soils an increase in bulk density from 1.4 to 1.8 significantly reduced root depth penetration in sandy loam soil. At lower soil moisture content the effect of bulk density was exacerbated due to increased soil strength.

Soil moisture influences root growth in two ways: availability of moisture to the plant; and the amount of air filled pore space. The distribution of water in the soil can influence the distribution of the root system, with a high water table restricting growth to the better aerated upper profile. Moisture content above about 40% sharply reduces root growth. Generally root growth decreases with decreasing moisture content, stopping when soil moisture is reduced to around 12-14% (Craul 1992). Different tree species vary considerably in their ability to tolerate and recover from periods of waterlogging (Smith *et al* 2001b). Young *Corymbia maculata* (Spotted Gum) and *Platanus* x *acerfolia* (Oriental plane) were able to initiate new root growth in waterlogged conditions, while *Platanus* x *acerfolia* (London plane) and *Lophostomen confertus* (Brush box) were not.

Plant roots consume large amounts of oxygen, about nine times their volume each day at 25C, and an adequate supply of oxygen in the soil is a growth prerequisite for many plant species (Greenwood 1969). Lack of oxygen effects the metabolic processes of both roots and soil micro-organisms, followed by disturbances to growth and to water and nutrient uptake (Glinski & Stepniewski 1985). Anaerobic conditions can also lead to increases in root disease causing pathogenic fungi. Roots appear to avoid anaerobic conditions forming shallow or surface rooting systems (Craul 1992). Soil temperature also effects root growth and distribution, as cell division and elongation are temperature dependant. Temperature ranges for different species range from a minimum of 1-11C, optimum 10-30C, and maximum 29-36C (Lyr & Hoffman 1967).

5.4 Street tree dilemmas

5.4.1 The hostile city

According to United States landscape architect James Urban

> *In the late twentieth century, urban trees are being forced to survive in city systems that are increasingly hostile to tree growth* (Urban 1989 p.93).

Street trees in cities face a life in a hostile environment in which their basic biological requirements may be difficult to satisfy. In her 1984 book on urban ecological design, *The Granite Garden*, Anne Whiston Spirn identified many of the challenges facing urban trees, illustrated in Figure 3 (Spirn 1984a p.175-179). The list is long and includes a range of factors (Simpson 1981). Urban trees face harsh climatic conditions including temperature extremes, heat stress (often associated with water stress conditions), leaf and trunk scorch from reflected heat from buildings and pavements, gusting winds (having a drying effect on urban trees, even if mechanical damage is not caused), and dense shade (effecting photosynthesis, stomatal closure and a range of growth factors). Urban trees also suffer from either too little (drought) or too much water (flood), with either drastically affecting the tree's ability to survive. Sealed surfaces and engineered stormwater systems reduce rainfall infiltration into the soil, which combined with urban microclimates leads to water stress. Poor drainage can lead to water-logging of the soil, creating anaerobic conditions.

NOTE:
This figure is included on page 57 of the print copy of the thesis held in the University of Adelaide Library.

Figure 3: Stresses on urban street trees

Source: Spirn (1984b) p.175.

Trees also suffer from a contaminated environment with polluted air, water and soils. This includes leaking gas mains poisoning roots, automobile exhausts and industrial pollution, dust particles that can suffocate the leaves of sensitive trees, contaminated runoff from sealed urban surfaces, and in northern latitudes de-icing salts. Sealed surfaces and leaf litter collection also interrupt the cycling of organic matter to the soil, leading to plant nutrient deficiencies. Sealed surface also limit gaseous exchange and aeration of the soil (Simpson 1981; Spirn 1984a; Mish 1986).

Trees may also be in conflict with services and utilities (both above and below ground), building footings, and surrounding paved surfaces (hardscape). Trees may even be damaged by the planting infrastructure installed to facilitate their growth, such as tree stakes and grilles. Tree canopies may also be in conflict with other elements of the built environment including buildings, verandahs, lighting and signage. Trees are also subject to both deliberate damage (vandalism) and accidental damage to tree trunks and canopies by cars and heavy vehicles.

Probably the main concerns are those below ground, due to the highly modified nature of urban soils (Craul 1992). Below ground trees must survive in compacted soils that may be '… as dense and infertile as concrete' (Spirn 1984a p.175), with limited water, nutrients, oxygen or anchorage for roots. Finally, street trees must survive in the very limited root space available between building footings, underground services, and other elements of the urban landscape. Tree pits dug in compacted soil may act as virtual 'tree coffins', restricting roots to the pit and limiting access to the necessary soil volumes for growth (Thompson & Sorvig 2008). In addition, tree pits dug in compacted soils can suffer from the 'tea cup syndrome', illustrated in Figure 4, with the tree's root system being starved of oxygen as a result of water-logging due to poor drainage from the tree pit into the surrounding compacted soil (Spirn 1984a).

NOTE:
This figure is included on page 58 of the print copy of the thesis held in the University of Adelaide Library.

Figure 4: The tea-cup syndrome

Source: Spirn (1984b) p.192.

Unsustainable planting practices often exacerbate the already hostile environment of the city. These include: undersized tree pits; tree pit designs that create problems of either too little or too much water; and the installation of excessive areas of impervious surfaces which prevent air, water and nutrients reaching the tree's root zone (Spirn 1984a).

Urban has observed that the hostile street tree environment has been exacerbated in recent years with the construction of wider roadways, larger buildings and more extensive infrastructure in cities (Urban 1989). More powerful construction equipment has also resulted in massive soil compaction (Urban *et al.* 1989). Space for trees has reduced with increased competition for limited space by vehicles, pedestrians and utilities (Urban 1996).

5.4.2 Street tree mortality

A number of writers, especially in the United States, have presented evidence of, and concern for, the shortened life span of street trees in inner-urban areas (Thompson & Sorvig 2000). Examples include tree replacement in footpath cutouts in Boston at ten years, and Washington D.C. at eighteen years (Foster & Blaine 1978). Urban foresters in the United States reported an average life span for 'down town' trees of thirteen years, compared with thirty-seven years for suburban trees (Skiera & Moll 1992). Tree deaths and removals soon after planting and establishment can be significant, and need to be included in calculations of urban tree life spans. Nowak (1990) reported 34% mortality after two years on a California boulevard. In three Wisconsin communities mortality rates were highest in the first year and declined until year four when normal lower attrition rates were achieved (Miller & Miller 1991). The size of the tree at planting is a relevant consideration, as larger girth trees are less susceptible to snapping by vandals (Edwards & Gale 2004). It has also been observed that street trees with limited soil volumes may exhibit rapid growth when young, which declines as the tree grows (Churack *et al.* 1994). Trees may also survive in constrained environments, but in a dwarfed condition. According to Miller

> *Lack of sufficient space for roots, combined with stresses from a variety of sources such as pollution, vandalism, higher urban temperatures, de-icing salts and so on prevent most street trees from reaching their biological potential in terms of size and age* (Miller 2007 p.222).

Tree death itself usually occurs as a consequence of a 'mortality spiral' in which 'pre-disposing' factors render the tree more susceptible to stresses such as pest, disease or drought, leading to its gradual decline and death (Harris *et al.* 2004). The 1989 Urban Forestry Commission Survey of urban trees in England found many to be in a poor state of health. Only 34% of trees less than fifteen years old were in good condition. Of the 15% recorded as damaged, only 1.5 p% was due to vandalism, the remainder being due to a hostile environment, bad detailing and poor maintenance.

Mean shoot extension on urban trees was half that of similar trees in nurseries or arboreta (Hodge 1991). A survey by the Scottish Development Agency concluded that the average survival rate for urban street tree schemes was 54%, with only one third of these being in good or excellent condition (Forestry Commission 1987).

5.4.3 Urban soils

Probably the main concerns are those below ground, due to the highly modified nature of urban soils (Craul 1992). According to one source

> *The single most important requirement for growing large, healthy, and long lived trees in the urban forest is the quality and quantity of the soil. It is estimated that up to 80% of all tree problems are soil related* (Georgia Forestry Commission 2001 p.20).

Poor below ground conditions can initiate a process of decline eventually resulting in tree loss.

> *Clearly we can no longer dig a hole in the pavement and expect trees to grow. Without attention to rooting needs, the average tree, after planting, begins to decline as soon as it outgrows the soil in which it was planted* (Urban *et al.* 1989 p.98).

The issue of urban soils is closely connected to the other major issue of surrounding trees with hard impervious surfaces. According to Edwards and Gale

> *The fundamental problem with planting in paving is the need for the tree to obtain sufficient water, oxygen, nutrition and anchorage to survive* (Edwards & Gale 2004 p.144).

Pavement finishes tend to be impervious to water infiltration, gaseous exchange, and nutrient cycling. In addition, the colour of paving will affect the heat buildup and surface reflection, and

> *Together they can create an almost desert like environment* (Edwards & Gale 2004 p.14).

Urban soils differ substantially from those in rural or forest areas. Their physical, chemical and biological properties have been modified as a result of the human activities of mixing[13], filling and contamination (Craul 1992). They also exhibit a high level of vertical and spatial heterogeneity, due to historical changes in land use (de Kimpe & Morel 2000).

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[13] Mixing refers to the mixing of original soil horizons, destroying soil structure. Filling refers to the introduction of new soil material. Contamination refers to the introduction of foreign materials in concentrations exceeding those normally found in natural soils.

Craul provides a definition of urban soils, based on an earlier definition by Brockheim (1974).

> *A soil material having a non-agricultural, man-made surface layer more than 50mm thick, that has been produced by mixing, filling, or by contamination of land surfaces in urban and suburban areas* (Craul 1992 p.86).

Craul identifies seven characteristics of urban soils which contrast with their natural counterparts (Craul 1992 p.88).

a) Great vertical and spatial variability;
b) Modified soil structure leading to compaction;
c) Presence of a surface crust on bare soil that is usually hydrophobic.
d) Modified soil reaction, usually elevated;
e) Restricted aeration and water drainage;
f) Interrupted nutrient cycling and a modified soil organism population and activity;
g) Presence of anthropeic materials and other contaminants;
h) Highly modifies soil temperatures regimes.

The nature of the soil will depend on its history of disturbance, with the extent of the disturbance increasing with proximity to urban centres, creating gradients in soil properties between rural, suburban and urban areas (McDonnell *et al.* 1993)

Craul also provides a useful comparison of the contrasting attributes of natural and urban soils (Table 19).

Table 19: Contrasting attributes of Natural versus Urban Soils

Natural Soil Characteristics	**Urban Soil Characteristics**
Formed by natural processes.	Formed by intense human activity.
Predictable boundaries and patterns	Very variable and unpredictable boundaries.
Continuous vegetation cover.	Usually sparse, weedy cover, if any, exposing the soil to high temperatures.
High level of microorganism activity.	Limited microorganism activity
Mostly gradual changes in depth.	Mostly abrupt changes in depth.
Few rooting barriers.	Many potential barriers to root growth, including compaction.
Few contaminants present.	Potentially many contaminants present.
Normal pH for natural soils.	Generally elevated pH for urban soils.
Source: Craul & Craul (2006) p22.	

Degradation of soils creates a variety of problems for street trees, most severe in highly urbanized sites, leading to impaired root function and tree health, and potentially increasing tree mortality (Roberts *et al.* 2006 p.82)

Compaction is probably the most serious threat to soil structure in urban settings.

Compaction occurs when a load is applied to a soil and the particles are forced into closer contact (Hillel 1998). Air is expelled and the volume of pore space is reduced (Brady & Weil 1999). Soil structure is also modified or destroyed, with the basic units of soil structure, the peds, being partially crushed (Roberts *et al.* 2006).

Bulk density and macroporosity are two useful indicators of soil compaction. Macroporosity, the arrangement of solid particles, is low when the particles lie close together. Macroporosity is reduced in compacted soils with the larger macropores between peds being compressed into smaller micropores. Bulk density is the mass of dry soil (oven-dried) per unit volume, including pore space. Soils with a high proportion of solids to voids (reduced pore space), such as compacted soils, have a high bulk density (Rivenshield & Bassuck 2007).

Human activities associated with urban development tend to result in soil compaction, which can be either intentional or unintentional (Roberts *et al.* 2006). Construction activities cause severe compaction, especially intentional compaction to prevent uneven soil settlement below building footings and pavements (Brady & Weil 1999). Engineers aim to achieve bulk densities as close to the maximum as possible. Maximum bulk density is achieved when soils are at their optimum moisture content. The Proctor test is used by engineers to determine maximum bulk densities (Proctor densities) for soils and optimum water content for compaction. Specifications usually require a soil to be compacted to 95% of maximum bulk density, as defined by a Proctor test (Hillel 1998). The required strength of soils below pavements can also be specified by the California Bearing Ratio (CBR). The CBR is the ratio of the force required to achieve a given penetration into a soil, to the force required to achieve the same penetration into a standard sample of crushed rock. Road pavement sub-bases are usually required to have a CBR of 15% or more (Department of Transport 1994). However the compaction of non-structural soils to CBR values sufficient to meet current specifications produces bulk densities which have been found to limit root growth (Roberts *et al.* 2006).

Soil compaction can also be unintentional, and any loading by pedestrian or vehicular traffic can lead to compaction. Urban soils, especially at street side locations, are also subject to vibration which can shake particles into tightly packed arrangements (Brady & Weil 1999). Unintended but severe compaction can also occur on construction sites as a result of activities such as vehicle movement and material storage (Roberts *et al.* 2006). It is also significant that the major contribution to soil compaction is made by the first vehicle moving over the ground (Smith 1987).

5.4.4 Impacts on tree growth

Trees planted in compacted soils can decline rapidly due to several interrelated factors. As compaction increases, soils exhibit an overall reduction in pore space (increased bulk density) and a reduction in the relative proportion of the larger pore spaces (macroporosity). Reduced soil porosity impacts on tree health in terms of: reduced surface infiltration; reduced water-holding capacity; impaired drainage leading to water logging; and decreased soil aeration (Roberts *et al.* 2006). Root growth is also restricted in compacted soils in two other ways: destruction of the larger macropore pathways for root proliferation; and the mechanical impedance to root elongation of increased soil strength (Kozlowski 1999).

Most trees grow best in well-aggregated, well drained soils with a bulk density less than 1.5 (Craul 1985). The normal range for clay soils is 1.0-1.6, with root restrictions occurring above 1.4. The normal range for sandy soils is 1.2-1.8, with root restrictions occurring above 1.6. Many compacted urban soils have a bulk density of 1.6-2.0 (Rivenshield & Bassuck 2007). Handreck and Black (1989) report that the bulk density at which root activity is limited is about 1.5 in fine textured soils, and 1.75 in sandy soils. In central Washington D.C., bulk densities from 1.7 to 2.2 were found under turf subject to high pedestrian traffic, compared with values less than 1.6 for less disturbed sites (Patterson 1977). Alberty *et al*. (1984) found that mean bulk densities on eleven construction sites, increased from 1.03 to 1.56 after construction, in site areas where compaction was unintentional and not required for engineering purposes, and which were intended for future landscaping. The ideal pore space for growing trees is around 50%, however Patterson found that soils in The Mall in Washington D.C. were as compacted as a brick, with pore space often less than 35% and in some cases as low as 13% (Urban *et al.* 1989).

Reduced infiltration

Infiltration refers to the entry of water at the soil surface. Infiltration rates are generally higher for coarse textured soils with large macropores (Bevan & Germann 1982), and where good soil structure has been created by old root channels, cracks and burrowing fauna, especially earthworms (Ehlers 1975; Bevan & Germann 1982; Kladivko *et al.* 1986). Infiltration can also be effected by textural discontinuities between layers with different hydraulic conductivities, and by the natural crusting of the soil surface under the impact of raindrops (Hillel 1998). Vegetation helps protect soil from crusting by intercepting raindrops.

Infiltration rates tend to be reduced in urban soils, where compaction leads to a loss of pore space, soil structure and macroporosity. Macroporosity is also lost due to loss of earthworms and other soil fauna (Pizl & Josens 1995). Reduced infiltration rates can also be exacerbated by: the formation of surface crusts caused by the accumulation of fine soil particles from crushed soil aggregates in the surface pores; and textural discontinuities found in urban soils (Roberts *et al.* 2006).

An important consequence of impeded infiltration is reduced runoff, especially during heavy rainfall events. In urban areas impervious surfaces are part of an engineered system, in which rainfall is diverted to drains. Such ‘pave and pipe’ systems tend to be ‘closed’, with no water leaving the system to infiltrate into the ground, reducing the amount of water stored in the soil for use by trees (Edwards & Gale 2004). Unintentional sealing of the soil surface, including crusting of unvegetated soils, and sealing by pollutants causing hydrophobic soils, also increases runoff (Craul 1992). Table 20 presents a summary of the impermeability of a range of urban surfaces.

Table 20: Impermeability of various surfaces to water and air movement

Finish	Impermeability factor
Asphalt or concrete	0.85-0.95
Paved with cemented joints	0.75-0.85
Paved with open joints	0.5-0.7
Blocks with open joints	0.4-0.5
Macadam roadway	0.25-0.6
Gravel roadway	0.15-0.3
Grassed areas	0.05-0.25
Wooded areas	0.01-0.2
Note: 1=maximum impermeability	
Source: Edwards & Gale (2004) P.145.	

Reduced water-holding capacity

The capacity of the soil to store water that is available for use by plants is the amount of water in the soil between field capacity and permanent wilting point. Field capacity is the water held in the soil after the macropores in a saturated soil have drained under gravity. Water remaining in the soil is held against gravity in the smaller pores under suction. Water in the very fine pores is held by very strong suction forces, too high to be extracted by plant roots. Most plants cannot take up water at potentials lower than -1.5MPa, known as the permanent wilting point. Only the water held in the soil between field capacity and permanent wilting point is available to plants (Roberts *et al.* 2006). Available water holding capacity depends on soil texture, which determines pore size and distribution. Loams and silts have the highest capacity. Sands have lower capacities as the high proportion of larger pores drain rapidly under gravity. Clays retain the most water after drainage, but a high proportion is held in very small pores making it unavailable to plants. Water holding capacity is also higher in soils containing more organic matter (Brady & Weil 1999).

Disturbances in urban soils reduce their water-holding capacity. Compaction reduces pore space and therefore water-holding capacity (although compaction of loose soils can increase water holding capacity by increasing micropore space). However compaction typically increases the proportion of fine micropores where water is held below permanent wilting point, resulting in lower water availability to plants (Roberts *et al.* 2006). Other characteristics of urban soils reducing water-holding capacity include: use of clay fills where water is held below permanent wilting point; use of very coarse fills which drain entirely under gravity; and lower organic content soils (Roberts *et al.* 2006).

Impaired drainage

Well structured and sandy soils drain easily, as water moves rapidly through the macropores when at high water content (i.e. high hydraulic conductivity). In fact, unstructured clay soils have hydraulic conductivities 100 times slower at saturation, and drain slower as the pore size distribution is dominated by micropores (Hillel 1998). Any disturbances that destroy soil structure and cause compaction can reduce drainage rates and make the soil prone to water logging.

Compacted urban soils are more prone to water logging due to the destruction of the larger macropores which enable good drainage (Brady & Weil 1999). In urban planting situations, textural discontinuities can result in water logging due to the properties of water movement at the interface. Textural discontinuities can occur between layers; and also where pockets of soil are surrounded by soil of a different texture. The latter is a common situation with street tree pits (Craul 1985). Craul named the effects of textural discontinuities on tree pit drainage as the 'teacup effect'. Poor drainage will occur from a tree pit dug in compacted soil (and backfilled with a high quality loam) into the surrounding compacted soil. When waterlogged, aeration of the soil in the tree pit is reduced, impairing the functioning of the root system. Tree pits dug in coarse gravel, the usual base for load-bearing pavements, can also be subject to waterlogging, as drainage from the loamy backfill will not occur until the water potential is high enough for the water held under suction in the finer pores of the backfill, to be released into the larger pores of the gravel. This will not be reached until the backfill is saturated or nearly saturated (Craul 1992).

Reduced aeration

Functioning roots require oxygen for aerobic respiration. Carbon dioxide is also produced as a by-product of respiration. Root health is therefore dependant on the ability of the soil to transport oxygen to the roots, and to remove carbon dioxide (Roberts *et al.* 2006). Gaseous transport in soils occurs along pathways of interconnected pores, and can be reduced by restricted pore connectivity. Soil aeration can be reduced due to: loss of macropore spaces; sealing of the soil surface; and water logging (Roberts *et al.* 2006). Compaction destroys soil structure and reduces macrporosity, reducing gaseous diffusion pathways gaseous diffusion rates. It also leads to an increase in the proportion of pores filled with water rather than air (water logging).

In urban soils aeration is commonly reduced by: surface fill; changing soil levels during construction; and covering the soil with impervious surfaces (Roberts *et al.* 2006). Water logging reduces aeration by closing aeration pathways with water filled pores, which is significant as the diffusion of gases is about 10,000 times slower in water than in air (Hillel 1998). In addition micropores have more discontinuities than macropore pathways, reducing oxygen diffusion. Oxygen diffusion is reduced in compacted soils, even if it is only surface compaction.

It is difficult to define critical thresholds for soil oxygen concentrations in the soil as it varies between tree species, and according to seasons. Tolerance to poor soil aeration varies between species, and some tree species have evolved on seasonally or permanently waterlogged sites (Hosner 1960; Beardsall 1981; Hitchmough 1994). Craul (1992 p.242) has compiled a table of species resistant or susceptible to soil compaction. Oxygen levels decrease with soil depth and on medium fine textured soils may be too low to support growth at 1.0-1.2 m depth (Biddle 1983; Cutler & Richardson 1989). Gilman has illustrated the effects of low soil oxygen on the rooting depth of a common street tree *Gleditsia tricanthos* (Gilman *et al.* 1987). In general oxygen concentrations below 10% gave been shown to restrict root growth (Patterson 1977; Day & Bassuk 1994). Root growth stops at concentrations of about 3% (Kozlowski & Davies 1975).

Mechanical impedance

Roots are unable to enter pores narrower than their root cap, unless they can exert sufficient pressure to displace soil particles and widen the opening (Craul 1992). With the loss of macropores and larger micropores, roots will have greater difficulty penetrating the soil.

Urban compacted soils are characterized by: the destruction of macropores, which reduces pathways for root proliferation; and increased soil strength which causes mechanical impedance to root elongation (Kozlowski 1999). Mechanical impedance is measured as penetrative resistance or bulk density. The pressure required to displace particles is higher in compacted soils. Bulk densities restricting root growth vary with soil texture and wetness, with soil strength higher in drier soils, and soils with higher clay content (Day & Bassuk 1994). In wet soils root penetration is limited at bulk densities of about 1.45 in clay soils and 1.85 in sandy soils (Kozlowski 1999). Capacity to overcome mechanical impedance appears to vary with species (Kozlowski 1999). Such variations make it difficult to develop definitive guidelines for acceptable bulk densities for landscaping (Alberty *et al.* 1984). Compaction can also lead to modified root distribution as well as reduction in overall elongation. Compaction on one side of a tree can be mitigated by compensatory growth on the less compacted side (Unger & Kaspar 1994). Similarly root proliferation may be restricted to cracks or old root channels in compacted soils (Passioura 1991). However modified root distribution may diminish the ability of the root system to extract water and nutrients as they must move over longer distances (Passioura 1991).

Soil temperatures

Soil temperatures depend on the energy balance at the soil surface, and the conduction of heat down through the soil. Surfaces absorbing high amounts of solar radiation become hotter, especially when dry, since heat cannot be dissipated by evaporation (Roberts *et al.* 2006). High soil temperatures can cause changes in the physiology of root tissue and impair root functioning (Gur *et al.* 1976) and root-shoot growth of trees (Graves *et al.* 1989). Some species and cultivars have a greater tolerance to higher temperatures (Wilkins *et al.* 1995). Detrimental effects of high soil temperatures may also be worse if combined with other stresses such as drought (Graves 1998).

Trees growing in locations surrounded by concrete and asphalt may be prone to impaired health and reduced vigor (Roberts *et al.* 2006). Surfaces of pavements and buildings reach high temperatures unless shaded (Kjelgren & Montague 1998). Soil temperatures tend to be higher under pavement than lawn or woodland. Temperatures on asphalt surfaces have been found to be 25C higher than surrounding turf surfaces, due to the absence of evapotranspiration (Kjelgren & Montague 1998). The predominance of asphalt, concrete and masonry surfaces in cities is an important cause of the 'urban heat island effect', and temperatures in cities have been found to be as much as 12C warmer than surrounding rural areas, on cloudless days (Oke 1987). Temperatures in soil below hard surfaces tend to be warmer in summer. In one study the mean temperature of the top 0.5 metre of soil was 4°C warmer below concrete than nearby lawn, and 7°C warmer than woodland soil outside the city (which was coolest due to shading by tree canopies and evapotranspiration) (Graves & Dana 1987).

Chemical properties

The chemical properties of urban soils have not been as well researched as those of natural, rural and forest soils. Very little is known except in relation to contamination by salts and pollutants (Roberts *et al.* 2006). Knowledge of nutrient availability is limited, leading to the assumption that urban soils are nutrient poor, which is not always the case (Pulford 1991).

There is a greater understanding of the problems caused by the interrupted cycling of organic matter (Craul 1985). Urban vegetation is limited in extent, and only small quantities of litter are returned to the soil due to the sealing of surfaces, and removal of organic material as waste (Craul 1985). Lack of organic matter recycling has implications for soil structure, soil fertility, soil biology (Roberts *et al.* 2006).

Interrupted cycling of organic matter can lead to nitrogen deficiency being the major limitation to plant growth in urban soils (Pulford 1991). Most nitrogen in soils exists in organic form unavailable to plants. Microbial action converts organic nitrogen into a form which can be taken up by plants roots, but this requires an adequate pool of organic nitrogen in the soil. Phosphate chemistry in urban soils is not well understood (Pulford 1991). Phosphorous compounds in the soil have low solubility and so low availability to plants. Uptake of phosphorous is aided by mycorrhizal fungae, so phosphate deficiency may occur where soil conditions inhibit mycorrhizal growth. Phosphorous also has low mobility in the soil and is generally concentrated in the upper layers, so stripping of topsoil in urban development can cause phosphorous deficiency (Craul 1992). The pH of soil is determined by the chemistry of the parent material, vegetation composition and soil amendments. Urban soils tend to have higher pH than rural soils for three reasons: the use of calcium or sodium chloride as de-icing compounds; use of irrigation water enriched with calcium; and the release of calcium from weathering of building rubble and building surfaces (Craul 1985). Urban soils are also subject to contamination by a variety of pollutants (Craul 1992).

Biological properties

A handful of soil can contain billions of living organisms forming a complex web vital to plant growth (Harris *et al.* 2004). Soil organisms decompose organic matter, fix organic nitrogen, transform nitrogen between organic and mineral forms, assist plants with nutrient uptake, or cause pathogenic or parasitic infections (Roberts *et al.* 2006). The biology of urban soils has not been well studied, but most reports indicate urban soils have reduced populations of soil organisms (in numbers, biomass and species diversity), including earthworms (which improve soil quality by digesting organic matter and mixing and aerating the soil) and mycorrhizal fungi (which form symbiotic relationships with plant roots) (Harris 1991; Pizl & Josens 1995).

5.5 Thinking like a tree

When designing urban streets we should try to 'think like tree', basing our designs on the biological needs of trees. United States landscape architect James Urban suggests that, to encourage the growth of large and healthy trees, five major parts of tree structure, both above and below ground, must be considered (Urban 2007).

According to Urban (2007 p.361)

> *When the area around the tree open to the rain and sun is less than 400 to 500 square feet (37.16m^2-46.45m^2) per tree, the following design guidelines should be followed to encourage the growth of large, healthy trees.*

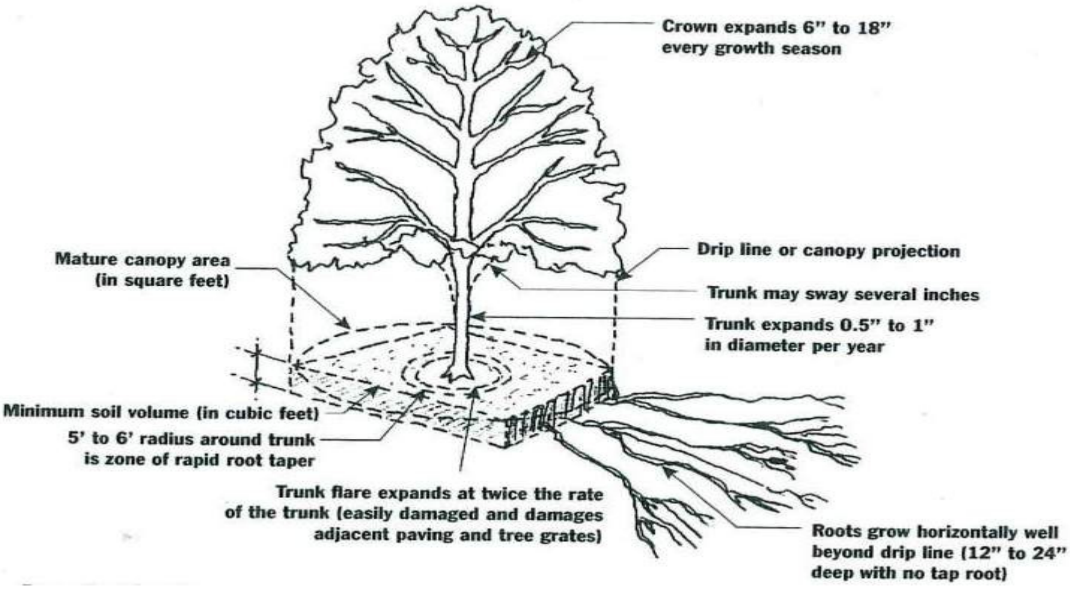

Figure 5: Tree components

Source: Urban (2007) p.361.

As illustrated in Figure 5, five major parts of the tree should be accommodated in the design process (Urban 2007 p.361).

a) ***Crown growth***. *The tree crown expands at a rate of 6 to 18 inches (15.2-45.7 cm) every growing season. Once the crown reaches a competing object, such as a building or other tree canopy, canopy growth in that area slows then stops. Eventually the branches on that side die. As canopy expansion potential is reduced, overall growth rate and tree health are also reduced.*

b) ***Trunk growth***. *The tree trunk expands at a rate of about 1/2 to 1 inch (1.3-2.5 cm) in diameter per year. As the tree increases in size the lower branches of the trunk lengthen. Tree trunks move considerably in the wind, especially in the early years of development, and are damaged by close objects.*

c) ***Trunk flare***. *At the point where the trunk reaches the ground, most tree species develop a pronounced swelling or flare as the tree matures. Trunk flare expands at more than twice the rate of the main trunk diameter and helps the tree remain structurally stable. Any hard object placed in this area, such as a tree grate or confining pavement, will either damage the tree or be displaced by the tremendous force of this growth.*

d) ***Zone of rapid root taper***. *Tree roots begin to form in the trunk flare and divide several times in the immediate area around the trunk. In this area, about 5 to 6 feet (1.5-1.8 cm) away from the trunk, the roots rapidly taper from about 6 inches (15.2 cm) in diameter to about 2 inches (5.1 cm). Most damage to adjacent paving occurs in this area immediately around the tree. Keeping this zone free of obstructions is important to long term tree health. Once a tree is established the zone of rapid taper is generally less susceptible to compaction than the rest of the root zone.*

e) ***Root zone***. *Tree roots grow radially and horizontally from the trunk and occupy the upper layers (12 to 24 inches) (30.5-61.0 cm) of the soil. Trees in all but the most well drained soils do not have tap-roots. A relationship exists between the amount of tree canopy and the volume of root supporting soil required. This relationship is the most critical factor in determining long term tree health. Root-supporting soil is generally defined as soil with adequate drainage, low compaction, and sufficient organic, and nutrient components to support the tree. The root zone must be protected from compaction both during and after construction. Root zones that are connected from tree to tree generally produce healthier trees than isolated root zones.*

5.6 Conclusion

Urban streets may often be designed without an understanding of the biological needs of trees. The biological needs of a tree are the same as those of a tree in the natural forest. The three natural processes of photosynthesis, respiration and transpiration must be sustained. The basic requirements essential to these processes comprise: oxygen; carbon dioxide; light; water; nutrients; and appropriate temperatures. To these could be added the requirement of adequate space, both above and below ground. Trees also play a significant role in a number of natural cycles which may be highly modified in urban areas: the water cycle, carbon cycle and nutrient cycles. Particular emphasis needs to be placed on the often forgotten ‘landscape below ground’ and the interactions of tree roots, soils and water in the urban environment. We now have a better understanding of the morphology of tree roots, and a new model based on a shallow spreading ’root plate’ rather than a deep, compact root ball. Soil properties are a vital consideration in terms of providing the tree with the necessary conditions for growth. Inappropriate soil conditions can comprise limiting factors to tree growth.

The city, however, comprises a very hostile environment for trees, in which the basic requirements for growth may be difficult to meet. Trees face a wide range of challenges both above and below ground, including climate, water, pollution, vandalism and damage, and conflicts with urban infrastructure. These problems are also often exacerbated by inappropriate planting practices. Two major issues are: planting trees in undersized tree pits dug in compacted soil; and surrounding trees with hard impervious surfaces. The hostile city, combined with inappropriate planting practices, often results in declining tree health, reduced tree life and tree deaths. A particular concern is the highly modified and degraded nature of urban soils. In particular, soil compaction, a universal problem in cities, has a number of impacts on tree growth, including: reduced surface infiltration; reduced soil water holding capacity; impaired drainage and water-logging; reduced soil aeration; and increased mechanical impedance to root extension. Compaction, and other factors, also modify soil temperatures and chemical and biological properties. It is concluded that, when designing urban streets we should try to ‘think like a tree’. One model is presented which takes account of five major parts of tree structure, both above and below ground: the crown; trunk; trunk flare; zone of rapid root taper; and the root zone.

6 Review of practices for growing healthy trees

6.1 Introduction

The following chapter comprises a review of urban streetscape design and street tree planting practices, derived from the literature. Practices have been classified under the following categories which have emerged from a review of the literature.

a) Above ground design
b) Below ground design
c) Water management
d) Infrastructure conflicts
    a. Hardscape conflicts
    b. Building conflicts
    c. Service conflicts

For example, Harris *et al*. (2004 p.222) identify three key issues related to trees planted in paved areas.

a) Providing adequate growing space above and below ground;
b) Ensuring that good below ground growing conditions are present in the form of soil fertility, aeration and drainage, as well as irrigation; and
c) Avoiding or treating damage to adjacent pavements caused by tree growth.

Sometimes there may be conflicts between different objectives.

> *Such is the dilemma of trees in urban areas. On the one hand, arborists endeavor to overcome poor soil conditions and limited space in pavement to ensure successful establishment and growth (they are not called "tree pits" without reason). On the other hand, good tree growth can cause problems to the infrastructure by lifting and displacing sidewalks and curbs* (Harris *et al.* 2004 p.222).

6.2 Streetscape design

6.2.1 Introduction

In urban streets, trees must compete for space, both above and below ground, with a wide variety of other streetscape elements and activities. The following section summarizes these design constraints within the street corridor. These relate primarily to 'above ground' installations and activities, but also include constraints imposed by some below ground services. An important consideration is that of the relative status of street trees in relation to other competing streetscape elements and functions. In the past, street trees have often been given lesser status and priority than the needs of engineering infrastructure and design agendas have been driven by function, risk avoidance and asset management. Design constraints include

a. Competition for available space.
b. Hardscape setbacks.
c. Pedestrian circulation.
d. Service clearances-underground.
e. Service clearances-overhead.
f. Traffic engineering constraints.
g. Public liability issues

Harris *et al.* (2004) point out that the provision of adequate above-ground space should be simpler than the provision of below-ground space, as the space is readily visible. However this does not explain the continuing practice of planting large trees in confined spaces, such as below power lines.

6.2.2 Competition for available space

Thompson and Sorvig (2000) point out that conventional tree planting specifications over the past century appear to be more concerned with squeezing plants into the minimum space, than with keeping plants healthy. Clients often demand maximum space for people and vehicles, and wish to maximize buildable and lettable area.

> *Space has monetary value, and when it comes to a choice between an extra foot of sidewalk and an extra foot of planter width, even the conventional specifications are often ignored* (Thompson & Sorvig 2000 p.118).

Within the road corridor there is competition for available space for a wide range of physical and functional uses: traffic lanes, car parking, bus lanes and indented bus bays and bicycle lanes. Within the verge there is also competition for space for: pedestrian circulation, property access, street furniture, signage, verandahs and canopies, and outdoor dining. Above and below ground there is also competition from engineering infrastructure, including: traffic control devices, street and pedestrian lighting, stormwater drainage, overhead power lines, and below ground services including water supply, sewerage, electricity, gas and telecommunications providers.

6.2.3 Setback and clearance codes

Authorities often require street trees to be setback minimum distances from other urban streetscape elements. Table 21 provides an example of a typical set of guidelines produced by the Adelaide City Council, which are advisory only (ACC nd).

Table 21: Adelaide City Council: guidelines for street trees.

NOTE:
This table is included on page 73 of the print copy of the thesis held in the University of Adelaide Library.

Source: ACC (nd)

In 1997 in South Australia the Public Utilities Advisory Committee (PUAC) prepared a *Code for the Placement of Infrastructure Services in New and Existing Streets 1997* (PUAC 1997). The Code includes consideration of street tree placement in relation to other street elements, and is used by a number of Council's as a guide to street tree planting. Table 22 presents street tree clearances based on acceptable solutions to achieve a set of specified performance criteria, drawn from this code.

Table 22: Street tree clearances

NOTE:
This table is included on page 74 of the print copy of the thesis held in the University of Adelaide Library.

Source: Public Utililties Advisory Committee (1997) p.27.

6.2.4 Hardscape clearances

In terms of kerb setbacks, a minimum 1300 mm separation is required between the kerb face and tree centerline to avoid tree root damage to the kerb and road pavement, and to provide for motorist safety (PUAC 1997). For footpath setbacks a minimum 1000 mm separation is required from trees to footpaths to minimize tree root damage to the footpath, and to allow clear and unobstructed pedestrian access (PUAC 1997). The PUAC Code requires a minimum separation of 1300 mm between a tree and a property boundary for building clearances (less when it is known that no future building will occur). This is of particular significance where masonry boundary fences exist, and where buildings are set back a short distance from the property boundary, as future building and wall construction are difficult to predict (PUAC 1997).

6.2.5 Footpath clearances

In terms of footpath widths, the *Austroads Guide to Traffic Engineering Practice, Part 13, Pedestrians*, provides guidelines for minimum clear width of footpaths (Austroads 1995). Specified clear widths are: 1000 mm ambulant disability; 1200 mm wheelchair and pram to pass; 1800 mm two wheelchairs to pass comfortably. 1800 mm therefore is a desirable minimum footpath width, but this may be reduced to 1200 mm if unavoidable. *Australian Standard AS 1742.1* also addresses disability access requirements (Standards Australia 2009). The above widths are minimum requirements only and local authorities may require additional width in high pedestrian areas. For footpath setbacks, a minimum 1000 mm separation is required from trees to footpaths in order to minimize tree root damage to the footpath, and to allow clear and unobstructed pedestrian access (PUAC 1997).

Footpaths are traditionally located adjacent to the property boundary, with trees planted in the verge between the footpath and kerb. This has a number of benefits including: providing a safe and enjoyable pedestrian experience; and reducing perceived width of the road pavement. In subdivisions in South Australia since the 1980s there has been a trend to locate footpaths adjacent to the kerb. This is intended to encourage residents to maintain their own section of verge, as an extension of their own property, especially where front fences are not required. Vehicle passengers can also step directly onto the footpath, however pedestrian, car door conflicts can occur. It also creates a less safe and pleasant pedestrian experience and visually widens the road corridor. In some cases footpaths may be also be located on one side of the road only (PUAC 1997).

6.2.6 Service constraints-underground services

Common Services Trench

In contemporary subdivisions, electrical, gas and telecommunications agencies may agree to place their services in a shared Common Services Trench (CST). This is preferably located adjacent to the property boundary, under the footpath, to facilitate service connections. A clearance of 100-500 mm between the trench and property boundary may be required for the installation of other service equipment, or 800 mm for stormwater infrastructure. A minimum separation distance of 1000 mm is required between a tree and a CST to protect services in the trench, to provide space for adequate root and trunk development, and to provide space for future trenching along the CST (PUAC 1997).

Sewer and water

Regulation 24 of the *Sewerage Act 1996* controls planting of trees by South Australian Councils, in proximity to sewer lines and connections (South Australia 1996c). Schedules 1 and 2 list 200 trees and shrubs that cannot be planted within 3.5 m (Schedule 1) or 1.5 m (Schedule 2) of any sewer line or connection without the consent of SA Water. In addition another 400 species are provisionally classified. In addition, Regulation 37 of the *Waterworks Act 1996* requires that trees and shrubs not be planted within one metre of any water main or service connection (South Australia 1996d). Older rubber ringed jointed sewers are more liable to root intrusion than more recent PVC sewers with solvent welded joints, however these may still be liable to damage from root growth due to crushing and displacement (PUAC 1997)

6.2.7 Service constraints-overhead services

According to Hitchmough

> *Of all the factors limiting the extent to which trees can be used to maximize the above benefits, the most significant is probably the conflict between overhead power cables and tree canopies* (Hitchmough 1994 p.282).

Fakes (2000) identifies two major issues: limitation of tree planting below or near overhead power lines; and the negative impacts of electricity supply authority pruning practices. Pruning issues include: aesthetic concerns; economic pressures; and declining tree health. A survey in New Orleans found a strong relationship between overhead power lines and poor tree condition due to repeated heavy pruning (Talarcheck 1987).

In all Australian states there are statutory requirements on electrical authorities to keep vegetation clear of power lines, however there is considerable variation in the way conflicts are managed (Hitchmough 1994). In South Australia under the *Electricity Act 1966* (Part 5) (Section 66) an electrical entity has a responsibility to keep public power lines reasonably clear of vegetation of all kinds (South Australia 1996b). Schedule 1 of the *Electricity (Principles of Vegetation Clearance) Regulations 1996* specifies clearance and buffer zones for overhead power lines on public land, which must be kept free of vegetation, in bushfire and non-bushfire risk areas (South Australia 1996a). Schedule 2 specifies prescribed distances in which tree planting is controlled, related to voltage, which is abstracted in Table 23.

Table 23: Prescribed distances in which tree planting is controlled (South Australia)

NOTE:
This table is included on page 76 of the print copy of the thesis held in the University of Adelaide Library.

Source: Schedule 2 Electricity (Principles of Vegetation Clearance) Regulations (1996a).

Within these prescribed distances, vegetation may be planted, but it must be from the species listed in Table 2 of the Regulations (vegetation with a mature height less than 3 m) or Table 3 (vegetation with a mature height between 3-6 m).

The traditional approaches to preventing and managing conflicts have been tree-based, preventing conflicts through restrictions on tree size and siting, and management of conflicts through tree pruning. Tree species selection criteria include size (small sized mature trees under power lines), shape (columnar trees next to power lines) and growth rate (slow growing species) (Bloniarz & Ryan 1993). Hitchmough also suggests selecting trees with an appropriate branch structure and canopy shape that can be trained around power lines, and employing dwarf rootstock (Hitchmough 1994). Siting criteria include, setbacks from power lines; and planting on one side of the street only, the side without power lines (Fakes 2000). Small stature trees, however, may be out of scale in wide streets and only be visually effective in narrow streets (Hitchmough 1994). Tree pruning, the main way of managing conflicts, is also not desirable in terms of the demand for high recurrent resources, and, even when undertaken by competent crews it can result in poor quality streetscapes (Hitchmough 1994). Hitchmough, however, considers tree based approaches a diversion from more appropriate engineering solutions.

> *Tree selection is an attractive means of addressing the problem that…from the perspective of the utility transfers responsibility away from the service provider* (Hitchmough 1994 p.282).

Hitchmough (1994) sees a parallel between the need for engineering solutions to overhead power line conflicts, and the need to better design building footings to reduce tree root damage. In both cases a fundamental engineering solution should be sought.

Engineering solutions include undergrounding of power, and aerial bundled cabling (ABC). Undergrounding of power is often cited as the preferred solution, and is mandatory in many new urban developments. However it has a two disadvantages: cost (often being undertaken on a 50/50 basis between the electrical authority and local council, and often prohibitive for high voltage lines); and possible root damage and difficulty in finding below ground space for relocation (Fakes 2000). Aerial bundled cabling is possibly the most useful innovation. With ABC a number of wires are bundled in a single insulated cable, allowing more relaxed clearance codes (reduced to a range between 0-500 mm (Fakes 2000).

At Virginia Tech in the United States, Bonnie Appleton is researching tree power line conflicts, including both conflict resolution measures (including natural, lateral and directional pruning) and conflict avoidance measures (including routing power lines to avoid trees, undergrounding power, and appropriate species selection). The two preferred species selection options realized to date are planting small trees under power lines, and tall upright trees alongside power lines. Virginia Tech also maintains a ‘Utility Line Arboretum’ to trial different species and cultivars (Appleton & Johnson-Asnicar 2002; Appleton *et al.* 2005)

6.2.8 Traffic engineering constraints

Clear zones

Policies of traffic management authorities are often based on the concept of roadside trees as a key risk factor for motorist safety rather than as an urban asset. Austroads publication *Urban Road Design* is the traffic engineers ‘bible’ to the geometric design of major urban roads (Austroads

2002). However its only reference to street trees or vegetation is under the topic of roadside safety (Section 14.3.4).

Risk management for roadside hazards is through the ‘clear zone concept’. The clear zone, which is defined by factors such as speed, traffic volumes and road geometry, is intended to be kept clear of non-frangible objects. Trees and other vegetation in the clear zone should be frangible (capable of being broken) with a mature trunk diameter less than 80-100 mm, and should not obstruct sight distances (Austroads 2002). Clear zones are seen as the largest impediment to roadside tree establishment on arterial roads in Victoria (Watson 2007b). New trees on declared roadsides must meet clear zone guidelines unless a barrier system is installed. In Victoria clear zone distances are calculated using the *Road Design Guidelines, Part 3* (VicRoads Design 2004). The required setback is determined by the design speed, traffic volume and road curvature. Only ‘frangible’ objects should be included in this zone. Woody limbs less than 100 mm diameter may be considered frangible (Road Construction Authority 1987). Requirements vary between Australian states, but the basic offsets are similar. The standards are likely to change, and a national guideline may be adopted in the future as an Austroads publication.

In the United States Wolf and Bratton (2006) have analyzed road crash data, including collisions with trees, differentiating urban and rural situations. They concluded that tree collisions in urban situations are less well understood, and that clear zone philosophies developed for rural settings may not be appropriate to urban areas if trees are to deliver their recognized benefits. More flexible context sensitive solutions may be required to meet community expectations as well as safety requirements. Future strategies should be based on research testing trees as devices which can enhance traffic safety, and risk assessment as an expression of community as well as engineering values.

Intersection sightlines

Historic memorable streets are often tree-lined, with regular tree spacings, and with trees planted all the way to intersection corners (Jacobs 1993). However, in the automobile age, safety concerns have resulted in trees being set back long distances from intersections, to maintain sight lines for drivers (MacDonald 2008). Traffic engineering design manuals by authorities such as the American Association of State Highway and Transportation Officials (AASHTO) recommend designing intersections with clear sight triangles to allow drivers to see potential conflicts, eliminating visual obstructions including street trees. In South Australia sight distance parameters are defined in Section 8 of *Urban Road Design*, and include the definition of an unobstructed sight triangle at intersections calculated from vehicle stopping distances (Austroads 2002 p.14). Figure 6 illustrates the unobstructed sight triangle concept.

Figure 6: Intersection sight triangle

Source: Transport SA (2001) p.14.

In the United States, MacDonald (2008) queries these restrictions for two reasons. Restricting trees may not solve visibility problems, as other objects can still block sight lines, including parked cars; and streets do not function as well as they should for pedestrians by providing comfort, legibility and shade. MacDonald has applied three dimensional modeling and concluded that street trees, if properly selected, spaced and pruned to branch high, do not create major visibility problems, and that parked cars in fact create more visibility problems. MacDonald concludes that, although further research is required, the AASHTO guidelines need to be re-evaluated.

Vegetation clearance

In South Australia the Commissioner of Highways has powers under the *Local Government Act 1999* and the *Highways Act 1926*, to undertake activities ensuring the safety of road users, the structural integrity of the road pavement, and the efficiency of the public transport system (Transport SA 2001). Road maintenance requirements include maintaining a vegetation clearance envelope. In urban or built-up areas the clearance envelope comprises a desirable vertical clearance of 5.0 m from kerb to kerb and a minimum 5.0 m clearance over the legal travel lanes. As illustrated in Figure 7 the clearance envelope is further modified on medians, where a clear height of 2.1 m is to be maintained, extending 1m into the median or to the nearest tree trunk. Such requirements may limit the minimum width of medians in which trees may be planted. Vegetation is also cleared to maintain safe sight distanced at intersections (Transport SA 2001).

NOTE:
This figure is included on page 80 of the print copy of the thesis held in the University of Adelaide Library.

Figure 7: Median clearance envelope

Source: Transport SA (2001) p.25.

6.2.9 Public safety and liability

Street trees can create issues of public liability and risk management which may act as a constraint on planting. The most common risks are property damage (tree roots encroaching on another's property, and trees or branches falling onto another's property) and personal injury to third parties (tree roots creating trip hazards, and trees or branches falling onto third parties) (Gardner 2005).

In South Australia a local council's responsibilities are defined under the *Local Government Act* (1999). Section 232 of the *Act* refers to trees. When a Council plants, or permits the planting of vegetation, it must have regard to: environmental and aesthetic issues; the use and construction of the road and any potential for interference with the road or its infrastructure; road safety matters; and impacts on nearby residents, businesses or advertisers. Section 245 deals with liability for injury, damage or loss caused by certain trees. A Council, however, is not liable for damage to property resulting from the planting of a tree in a road, or from an existing tree in a road, whether planted by Council or not, unless the owner or occupant of an adjacent property has advised Council in writing of the risk, and Council has failed to take reasonable action in response. Under Section 55A (Vegetation clearance schemes) an electrical authority may also agree to a vegetation clearance scheme with a Council governing the way vegetation is kept clear of power lines (South Australia 1996a).

Strategies for Crime Prevention through Environmental Design (CPTED) have also been adopted by authorities in Australia and overseas, which may act as constraints on street tree planting. The basis of CPTED is the design of the built environment and public realm to reduce both the fear and incidence of crime. CPTED principles which effect tree species selection and location include maintaining adequate natural surveillance and sight lines, with public spaces kept clear of vegetation which may obstruct sightlines, reduce lighting levels and create hiding places. In South Australia CPTED principles can be incorporated in statutory *Development Plans* prepared by local Councils (Planning SA 2004).

Table 24: Summary of above ground constraints and practices

Topic	Constraint	Practice
Competition for space	Road corridor space	Priorities
	Footpath space	Priorities
Hardscape constraints	Kerbs	Setbacks
	Footpaths	Width, location
	Buildings	Setbacks
Below ground services	Sewer and water	Setbacks, species lists
	Other	CST
Power lines	Tree based practices	Species lists
		Location
		Pruning
	Infrastructure based practices	Routing
		Undergrounding
		ABC
Traffic management constraints	Clear zones	Setbacks
	Sightlines	Intersection triangles
		Clearance envelopes
Footpaths	Width	Minimum requirement
	Location	Property boundary
		None or one side only

6.2.10 Conclusion

Street trees are but one element in the urban streetscape and must compete for valuable urban space with a range of other physical infrastructure and functions. Tree species selections, and planting locations, are also constrained by setback or clearance requirements from other urban infrastructure, including hardscape elements, underground services and overhead services. Prevention and management of conflicts with overhead power lines constitute a significant impact on street trees. Safety requirements of traffic management authorities, including clear zones and intersection sightlines, are also a significant constraint on tree planting and management. Many of these requirements may be summarized in local authority codes.

Resolution of conflicts has tended to be tree based, focusing on tree species selection, planting setbacks and pruning practices. An alternative engineering based approach would be more beneficial to promoting the interests of the urban forest. This would include engineering solutions to tree and infrastructure conflicts, in terms of both service locations and their design. It would also include a re-examination of traffic safety standards which recognizes both safety requirements and the community benefits delivered by street trees.

6.3 Design below ground

6.3.1 Introduction

There is an intuitive relationship between the size of a tree and its below-ground growing space. A tree should require an adequate soil volume to provide it with the resources necessary for growth. According to Harris *et al.* (2004 p.222)

> *There is a clear and direct relationship between the volume of below ground growing space and tree size: the greater the space the greater the tree growth.*

According to Costello and Jones (2003 p51) three questions must be asked.

a) *What volume of soil is required for a tree of a particular size?*
b) *How much soil volume is available for root development?*
c) *And, how can the soil volume be increased?*

Craul (1992 p293) however, provides a qualification

> *One of the major questions that must be answered in urban tree planting is that of how much soil volume must be furnished to each tree. Unfortunately it is not simply a question of 'the more the better'.*

In a recent book, Timothy and Philip Craul (Craul & Craul 2006 p.43) identify the following range of soil related factors to consider in the design of the 'pedosphere' or below ground space.

a) *Available soil volume for adequate root growth over the life of the tree and/or other plants, and for mechanical support.*
b) *Infiltration and available volume of soil moisture.*
c) *Water drainage of the soil itself and the drainage of the element.*
d) *Aeration of the soil.*
e) *Amount and availability of plant nutrients.*
f) *Relative heat loading of the plant palette.*
g) *Exposure to toxic or other harmful factors.*

Soil volume requirements can also be considered in terms of the root/shoot ratio (the ratio of the dry weight of the below and above ground parts of the tree). For most species this is in the range of 1:10 to 1:3 (Biddle 1998), and generally between 1:5 to 1:6 (Harris *et al.* 2004). The ratio depends on plant age, the proportion of crown decreasing as the tree matures. Conversely root volume is initially greater than crown but reverses as the tree grows. The root system can control the size of the crown and the ultimate size of the tree (Biddle 1998).

6.3.2 Required soil volumes

Traditional urban street tree planting practices have often involved digging a hole, of sufficient size to accommodate the rootball, in compacted soil which is hostile to root growth beyond the excavated tree pit. Soil surrounding tree pits is typically hostile to root growth due to severe compaction, restricting root growth to the confines of the tree pit (Kristoffersen 1999).

In 1992 Craul cited traditional street tree pit dimensions of 1.2 m x 1.2 m square by 0.6 m deep, with a rootable volume of about 0.86 m^3 (Craul 1992).Many tree pits were much smaller than this, some as small as 0.6 m x 0.6 m and 0.9 m deep (0.32 m^3 volume), containing very poor specimens. Urban (1996) suggests that these planting specifications developed from tree planting practices on large estates with good soil, but are inappropriate for planting in city centres.

Urban and others describe such tree pits as tree 'tombs' or 'coffins'. The effects of restricted rooting volume on tree size, growth rate, health and mortality have been noted by a number of observers (Krizek & Dubik 1987; Kopinga 1991; Urban 1996; Schwets & Brown 2000). Street trees must often survive with a fraction of the below ground resources required to grow to maturity. They are therefore vulnerable to resource deficiencies, especially water, unless provision is made for alternative soil resources (Lindsey & Bassuk 1992). According to Biddle (1998 p.8)

> *Trees planted in low soil volumes generally have shortened lives and do not meet aesthetic/design requirements.*

Thompson and Sorvig (2000 p.118) also discuss the effects of restricted soil volumes.

> *… inadequate planting structures, particularly those with too little soil volume, are the leading cause of an epidemic of urban street-tree deaths.*

According to Edwards and Gale (2004 p.148)

> *Both research and observation suggest that the larger the tree pit, the greater likelihood of success.*

Published estimates of required soil volumes are usually of two main types. Some are empirically based on observations of existing urban trees (Helliwell 1986; Urban 1989). Others are based on the design of soil volumes to meet the water demands of trees, including soil volume and irrigation for containerized plantings (Lindsey & Bassuck 1991). Estimates tend to vary widely due to differences in soils, climate and assumptions regarding tree species and size. It is also difficult to predict how tree roots will colonize planting sites and increase accessible soil volumes in urban situations (Frank 2003). Frank (2003) provides a useful review of some common soil volume calculation methods. Table presents a summary of a number of such estimates from various sources.

Table 25: Estimates of required soil volumes

Source	Estimate	Notes
Perry (1985)	An area of approx. 6.5 m x 6.5 m (19 m^2).	For a 75 mm caliper tree to grow quickly to 300 mm caliper
Kopinga (1985)	7 m^3	Minimum, not optimum, for growth of individual elms in The Netherlands
Helliwell (1986)	200 m^3 for a 20 m tree with 12 m crown.	For very large trees in southern England. Anecdotal rule-of-thumb method.
Urban (1989)	Available soil, minimum 8.5 m^3 for tees with adequate vigor, 17 m^3 for healthiest trees.	Examined nearly 1500 trees in five eastern US cities.
Urban (1990)	Planting sites less than 3 m^3 cannot sustain long term growth. Increased surface area more beneficial than increasing depth below 600 mm, except for large growing trees.	Examined thirteen 11-27 year old plantings in US cities.
Kopinga (1991)	43 m^3	
Lindsey & Bassuck (1991)	On average 0.06 m^3 of soil volume for every 1 m^2 of crown projection.	Based on measuring transpirational loss from mature trees without supplementary watering. Applies in most US climatic zones except desert regions with high evaporation and little rainfall.
Urban (1992)	Produced graph which quantifies relationship between tree size (trunk diam. and crown projection) and required soil volumes.	Averaged data from Perry (1982), Kopinga (1991) and Lindsey & Bassuck (1991).
Lindsey & Bassuck (1992)	5 m^3	To sustain a 'typical specimen tree' through summer. Empirical relationship between evaporation and tree size.
Urban (1996)	0.03 m^3 of useable soil for every 0.2 m^2 of mature canopy.11 m^3 (if other soil in locality with some capacity for root development).	
DeGaetano (2000)	Varies	Refined Lindsey and Bassuk (1991) method using daily, rather than average, climatic data to estimate soil volumes and irrigation specifications.
Urban (2008)	34 m^3 for a large shade tree (22 m^3 minimum).	
Landcom (2008)	5-15 m^3 for small tree (4 m diam. canopy) 20-40 m^3 for medium tree (9.8 m diam. canopy) 50-80 m^3 for large tree (16 m diam. canopy)	Street Tree Design Guidelines for new subdivisions in NSW. 1m deep, unobstructed root volume.
Source: Compiled from various sources as stated.		

Published soil volume estimates therefore vary widely, but generally appear to be much greater than the space allocated to urban trees in the past two decades (Roberts *et al.* 2006).

Frank (2003) compared a number of methods for estimating the soil volumes for a London Plane (*Platanus x acerfolia*) in Melbourne with no irrigation (assuming a tree 16 m high, with a 15 m diameter canopy, and trunk diameter of 45 cm at 1.4 m height). His calculations of required soil volumes using seven different methods are presented in Table 26.

Table 26: Comparison of soil volume methods for a tree in Melbourne

NOTE:
This table is included on page 85 of the print copy of the thesis held in the University of Adelaide Library.

Source: Frank (2003) p.14.

In 1985 Perry estimated that an area of approximately 6.5 m by 6.5 m by 45 cm deep (19 m^2) was required for a 75 mm caliper tree to grow quickly to 300 mm caliper (Perry 1985). James Urban has produced a widely published graph which attempts to quantify the relationship between tree size and required soil volume (Urban 1992 p.89).

Urban averaged data from a number of sources (Perry 1982; Kopinga 1991; Lindsey & Bassuck 1991) to relate soil volume to tree size as measured by both crown area and trunk diameter. The graph, though not precise, gives a useful indication of approximate soil volume requirements. The graph, presented in Figure 8 has been reproduced in a number of publications including the 2007 edition of *Landscape Architecture Graphic Standards* (Urban 2007).

NOTE:
This figure is included on page 86 of the print copy of the thesis held in the University of Adelaide Library.

Figure 8: Soil volume required

Source: Urban (1996) p.77.

Urban (1996) stresses that soil quality is critical in calculating useable soil volumes, and that useable volume can include soil sources that the tree can access beyond the actual tree pit. Urban defines soil volume as all the soil that is available to the roots of a tree which is of a suitable quality for root growth (well drained, uncompacted and possessing adequate pore space). The maximum depth for this calculation is usually 75 cm. Similarly Craul (1992) emphasizes the need to consider other soil limiting factors as well as soil volume. Never-the-less the graph does indicate that soil volumes provided in a typical urban tree pit tend to be well below the optimum requirements.

The Crown Projection Method (CPM) is a popular method for estimating soil volumes. Researchers at the Urban Horticulture Institute at Cornell University developed a step-by-step method which assesses crown projection (drip line) and allows 0.6 m^3 of soil for every m^2 of crown projection (allowing 1m deep root depth) (Trowbridge & Bassuk 2004). Watson and Himelick also use the CPM but suggest that root space should be 60 cm deep within the crown projection (Watson & Himelick 1997). This is supported by Gilman (1997) who found that fine root density is greater within the canopy than beyond. The formula can be adjusted for columnar and fastigate tree shapes, using mature tree height as the basis of the equation.

Lindsey and Bassuk (1991) extended the CPM further developing a formula for specifying soil volumes based on the water demand of trees, with soil water holding capacity as the limiting factor. The method involved estimating crown projection area, evapotranspiration rates and soil moisture holding capacity to derive required soil volume. This was derived from a study by Rakow (1987) relating container size or soil volume, water holding capacity and growth performance. DeGaetano (2000) refined Lindsey and Bassuk's approach to include daily variations in weather and estimated irrigation frequency.

Hitchmough (1994) has derived a calculation method based on Lindsey and Bassuk's work, assuming zero precipitation capture. It is simplistic and does not account for extreme site conditions, however it uses readily available information and at worst provides a useful guide to tree pit adequacy (Edwards & Gale 2004). The Hitchmough method involves the following steps (Fieldhouse & Hitchmough 2004 p.150).

> **A Estimate daily water use of the tree (litres)**
> =Leaf area index x Evaporation ratio x Canopy size x Mean daily evaporation rate from site in peak demand period/ 100
> **B Calculate soil volume required (based on water holding capacity of soil)**
> The soil volume required to provide one day's water supply to the tree
> =Daily water use (litres) / Average water holding capacity of the soil (WHC)
> **C Insert rainfall interval (number of days without significant rainfall or irrigation)**
> Total soil volume required=Soil volume that provides one days supply of water x Rainfall interval

Clark (2003 p.33) uses a simpler formula using tree caliper as percentage of tree height, which provides a useful guide only. Soil volume (m^3) = Height (m) x Caliper (mm) divided by 100.

Frank (2003) concluded that the higher volumes would not be achievable in confined street situations. The CPM was the simplest method to apply, while the Clark (2003) method modifies CPM and is also easy to apply. The Lindsey and Bassuk (1991) method was the most comprehensive, but also the most difficult to apply.

Tree spacing

The issue of tree spacing is related to that of soil volumes. Tree spacing may often be decided for aesthetic or design reasons, rather than biological requirements, creating long term problems of tree health and survival. In an interesting historical precedent, Frederick Law Olmstead anticipated mature tree size when he planted an avenue of tulip poplars in North Carolina at 50 feet (17 m) spacing, with 30 feet (10 m) between rows (Craul 1992).

There is a tendency, especially amongst landscape architects, to plant young trees close together for immediate visual effect. However this can lead to future management costs as closely spaced trees will be more difficult to prune as they mature, mutual shading may create more deadwood; and overcrowding may cause stress, making trees more susceptible to disease. Urban (1996) recommends planting trees at nine to ten metre spacings so that canopy dieback does not occur. Trees planted close together for instant effect can be thinned out later, however this must be done before their crowns become too large, and removals may result in public objections (Miller 2007). For example such a situation has recently occurred in South Australia when the City of Burnside attempted to remove an avenue of historic but senescent elm trees (Draper 2009).

Local authorities may have spacing standards, which may be community-wide, or related to mature tree size. For example 7 m for small trees, 10 m for medium sized trees, and 10 m for large trees (Miller 2007). Another spacing consideration may be the demand for a tree in front of each residential property. Kalmback and Kielbaso have reported that a planting density of one tree per home satisfied the majority survey respondents (Kalmbach & Kielbaso 1979).

The following section provides a review of practices aimed at providing urban trees with enhanced soil volumes. Research in the United States in the last ten or so years, by researchers such as James Urban, Jason Grabosky, Nina Bassuk and others, has led to significant changes in industry standards for urban tree planting (Trowbridge & Bassuk 2004; Urban 2007; 2008). Recommended practices cited in *Sustainable Landscape Construction* by Thompson and Sorvig (2000) included increasing soil volumes per tree, the use of structural soils and suspended pavements, and the installation of a 'continuous root trench'.

6.3.3 Soil modification and replacement

Existing unsatisfactory soils can be remediated or replaced. However urban soils, once disrupted, are difficult to enhance through remedial treatments, and can be costly to replace (Craul 1992). Hand or mechanical cultivation of compacted soils can increase soil porosity and reduce bulk density (Rolf 1993). Soil compaction can also be alleviated with the addition of soil amendments (Brady & Weil 1999). Incorporation of organic matter can improve soil structure, enhance aeration and provide a source of nutrients. However Craul (1992) recommends that organic matter should not exceed 5% or settlement may occur over time, lowering the rootball, leading to collar rot and infrastructure displacement.

There are mixed views regarding the desirability of planting urban trees using amended backfill. Experiments have shown that the effects of compaction can be alleviated by improving the quality of the backfill soil (Day *et al.* 1995). Trees in compacted soil were shown to grow better with amended backfill, but only as long as drainage was adequate (Day & Bassuck 1994a). Another recent experiment showed that amendment of compacted soil with organic matter increased the potential for root growth, even when the soil is re-compated (Rivenshield & Bassuck 2007). Others have found that soil amendment has little or no benefit to tree establishment. Current best planting practice recommends against the use of amended backfill in urban tree pits, as amended backfill creates an interface between the tree pit and the surrounding compacted soil, impeding the movement of soil water, resulting in either drought or water-logging of the tree pit (Harris *et al.* 2004).

Mulching of soils has been shown to have a wide range of benefits. These include: conservation of moisture at the soil surface; moderation of soil temperatures; reduced compaction by traffic; reduced soil erosion; improved soil fertility and structure; protection of roots from mechanical damage; and reduced weed growth (Roberts *et al.* 2006). It has also been shown that, with time, mulching can help rebuild soil structure and improve the rooting environment (Watson 1988a). However, due to its perceived benefits, there is a tendency to over-mulch, which can result in reduced water and gaseous exchange between the soil and the atmosphere, so mulching should not be applied deeper than 15 cm, with 8-10 cm optimal (Roberts *et al.* 2006).

Replacement of poor quality soil with an improved soil is an option, but it has a number of limitations including: cost; small scale replacement creating changes in soil texture and barriers to root extension; and being contrary to currently accepted best practice of using unamended local soil as backfill in tree pits (Harris *et al.* 2004). While attempts have been made at soil replacement around existing trees, it is usually done prior to planting (Watson 1988b)

6.3.4 Structural (engineered) soils

Introduction

In the past two decades engineered or 'structural soils' have been developed in the United States and Europe. These all represent an attempt to extend the tree rooting zone beyond the confines of the tree pit, below the surrounding hardscape in highly developed urban settings. Structural soils are one attempt to reconcile the conflicting requirements of providing both the necessary engineering support for pavements, while still providing a satisfactory growing medium for tree roots. Traditionally there has been a conflict between these engineering and biological requirements. Pavement sub-surfaces need to be compacted to meet the specified load-bearing requirements. However compacted soils do not provide a satisfactory growing medium for tree roots.

Engineering requirements are generally for sub-surfaces to be compacted to within 95% of their peak density, to prevent settling under design loads (Roberts *et al.* 2006). Road and pavement base layers are also usually gravel or sand with little silt or clay, and a low capacity to retain water or nutrients (Bassuk *et al.* 1998). The biological requirements for root growth, however, include: low bulk density between 1.45 for clay and 1.85 for sand; a distribution of pore sizes providing adequate storage capacity for available water, and for good drainage and aeration; and sufficient fertility to provide an adequate supply of macro and micro-nutrients (Roberts *et al.* 2006).

It is important to recognize that structural soils comprise a 'family' of soils rather than a single commercial soil. In their most recent edition of *Sustainable Landscape Construction*, Thompson and Sorvig (2008 p.138) identify four structural soil types.

- Natural compaction resistant sandy loams
- Sand based Amsterdam tree soil
- Lightweight porous-aggregate mixes
- Crushed stone and sand mixes

Perhaps the most widely recognized engineered soils are those known as 'skeletal' or 'gap graded' soils, in which interlocking crushed stones provide a load bearing matrix, while the voids between the stones are filled with loosely compacted soil which provides a growing medium for tree roots. The 'skeletal' soil concept is illustrated in Figure 9. The best known skeletal soil, known as CU-Soil , was developed in the 1960s at Cornell University in the United States (Grabosky & Bassuk 1995). Structural soils were also developed independently in Europe, notably in The Netherlands in the 1970s (Couenberg 1993) and in Denmark in the 1990's (Kristoffersen 1998). In the last decade structural soils have been considered a viable option in highly constrained and fully paved urban sites (Costello & Jones 2003). Structural soils have typically been installed below pavements either as an extended rooting zone around tree pits, or in narrow trenches connecting tree pits (Thompson & Sorvig 2008).

NOTE:
This figure is included on page 91 of the print copy of the thesis held in the University of Adelaide Library.

Figure 9: Skeletal soil concept

Source: Roberts, Jackson & Smith (2006) p.98.

Amsterdam soil

Amsterdam Tree Soil was developed in The Netherlands in the 1970's (preceding the development of CU-Soil), in response to the decline of trees in Amsterdam due to unfavorable soil conditions. In addition to normal urban soils issues, Amsterdam is built on a heavy clay subgrade that limits plant growth (Couenberg 1993; 1998). The soil mix is predominantly a medium-coarse silica sand (approximately 90%), with small amounts of organic matter (4-5% by weight) and clay (2-4%), to add capacity for water and nutrient retention (Couenberg 1993). The components are mixed prior to installation. Depth is limited to one metre as aeration is too poor for root growth at greater depths. Compaction of the soil is specified in terms of penetrative resistance rather than bulk density, which must be 1.5-2.0 MPa after compaction (the equivalent of compaction to 70-80% of peak density). Root growth is not impeded at such density, however it is less than that normally specified for load bearing soils (usually 95% of peak density).

Despite its lower compaction levels, the soil has been successfully used to construct tree pits under footpaths, and under light vehicle parking. However it cannot be used as an alternative base for road pavements or footings. It does however allow for the installation of larger tree pits in urban areas. The basic tree pit installation in Amsterdam allows for greater extension of the pit below the surrounding paving (Couenberg 1993). Amsterdam soil has proven effective in Europe where it is frequently used (Connery 2009). An Amsterdam-derived soil is marketed in the United Kingdom by Heicom as Tree Sand or Tree Soil, a mix of washed, semi-rounded silica sand and organics (http://www.treesand.co.uk/site/pages/ui_tree-sand.html). Heicom recommends, as a guide only, allowing approximately 5 m^3 of soil per tree.

CU-Structural Soil

Probably the best known skeletal soil was developed at the Urban Horticulture Institute at Cornell University. It comprises a load bearing soil with a California bearing ratio (CBR) of 50 or greater which also provides for root growth (Grabosky *et al.* 1998a; Grabosky *et al.* 1998b). CBR is a standardized measure of load bearing capacity of pavement materials with acceptable values ranging from 40 to 80 (Grabosky & Bassuk 1996). The specification has been patented and trademarked as CU-Structural Soil or CU-Soil. The soil differs from Amsterdam soil in that evenly graded angular stones are used as the structural component, rather than silica sand.

The soil comprises: a stone component of 20-35 mm angular crushed stone (80%); a soil component of preferably clay loam soil, with 2-5% organic matter, occupying the voids between the stones (20%); and a small amount of hydrophilic gel to help bind the stones during transportation. An appropriate ratio of stone to soil (approximately 13-22% soil by weight) is critical to success, as excess soil will prevent the formation of a stable soil skeleton after compaction, as the stones must physically touch and interlock, transferring loads at the contact points (Grabosky *et al.* 1998a). Soil and stones are mixed prior to installation in a rotary mixer. During installation the stone matrix is compacted to within 95% of peak bulk density and a CBR greater than 50. The soil within the mix is protected from compaction by the stone skeleton. Day and Dickinson provide detailed information on soil specifications and mixing procedures (Day & Dickinson 2008)

The developers of CU-Soil also provide data on its aeration, water-holding and biological properties. Water-holding capacity is necessarily limited by the low proportion of soil in the mix, but was improved with the use of a hydrogel. A mixture with 16.6% soil, by dry weight, had a water holding capacity of 12.9% by volume, similar to a sandy loam (Grabosky *et al.* 1998b; Brady & Weil 1999). Aeration of structural soil below pavements exhibited concentrations well above 10% at a range of depths. In comparison oxygen concentrations in standard compacted subgrade are much lower, reaching 3% at depths which are saturated from poor drainage (Bassuck & Grabosky 2000). Fertility is determined by the nutrient status of the soil component and can be improved with fertilizer.

NOTE:
This figure is included on page 93 of the print copy of the thesis held in the University of Adelaide Library.

Figure 10: Extended rooting zone using structural soil

Source: Bassuk, Grabosky & Trowbridge (2005) p.160.

CU-Soils are intended to extend the rooting zone beyond the tree pit under adjacent paving, rather than serve as a backfill for tree pits, however trees can be planted directly into the structural soil to avoid creating an interface between the tree pit and adjacent soil. Figure 10 illustrates a typical installation of CU-Soil under a street footpath. Applications of the soil have been made in many locations around the world, primarily in North America, but also in Australia. Detailed information regarding the soil is available online at Cornell University (http://www.hort.cornell.edu/uhi/outreach/csc/). CU-Soil is marketed in the United States by Amereq Inc. (http://www.amereq.com/pages/2/index.htm).

Danish Forest and Landscape Institute

Structural soil mixes were also developed independently in Denmark in the 1990s. A number of mixes are available which are similar in concept with a 32-150 mm diameter load bearing component (using crushed rock, brick or lava) mixed with approximately 30% soil by volume. Stones and soil are mixed during installation, by compacting the stone on 15-25 cm layers and sweeping or watering soil into the voids (Kristoffersen 1998; 1999). Preliminary field testing of more than 800 trees installed in structural soils at 38 locations in Denmark indicated that the mixes with load bearing crushed granite, lava or brick provided a suitable growing media for trees, and problems of limited load bearing capacity, frost heave or settling were not observed (Kristoffersen 1999).

Carolina Stalite Soil

The Carolina Stalite Company has developed a structural soil using a lightweight, porous kiln expanded slate which takes the place of the load bearing rock used in CU-Soil. This provides additional water and air holding capacity, when mixed with 20% sandy loam (Costello & Jones 2003). Day and Dickinson (2008) provide a comparison of CU-Soil and Carolina Stalite, presented in Table 27, as well as information on soil specifications and mixing procedures.

Table 27: Comparison of CU-Soil, Carolina Stalite and silt-loam soil.

NOTE:
This table is included on page 94 of the print copy of the thesis held in the University of Adelaide Library.

Source: Day & Dickson (2008) p.9.

Air entrained soil

In the 1980s United States landscape architect Henry Arnold also independently developed a soil mix he called ‘air entrained soils’. The soil predates CU-Soil and differs through the use of a porous aggregate, such as expanded slate or shale, rather than a dense stone matrix. His mix uses 60-65% porous aggregate, 5-10% organic matter, and loam topsoil (Thompson & Sorvig 2008). The soil is not patented, nor is it backed by the extensive body of research carried out on CU-Soil. Rather, it has been applied on a regional basis to suit local conditions (Ferguson 2005).

Davis Soil

Davis soil has been developed at the University of California from local inexpensive volcanic rock, as a less expensive option to importing Carolina Stalite soil from North Carolina. It comprises 75% porous volcanic rock and 25% loam, by volume. While being an engineered soil, it is not considered a true structural soil as it cannot support vehicle loads. However it does have high porosity, around 40%, and can be used under pedestrian paving to create suitable growing conditions for trees, and to allow infiltration and storage of stormwater runoff (Day & Dickinson 2008; Xiao & McPherson 2008).

SPACE Soil

In Adelaide, South Australia, David Lawry has developed a structural soil utilizing recycled municipal water treatment residues. This colloidal based structural soil is known as SPACE

(Structural Permeable Aerated Compacted Earth). Unique to Adelaide there are now a number of successful trial sites around the city where SPACE has been installed beneath pavements. SPACE soil was recently installed in a 60 m x 6 m, by 600-800 mm deep trench below paving at the Adelaide Central City Bus Terminal, to provide a growing medium for twelve Spotted Gums (*Corymbia maculata*) (Kelley & Stevens 2008).

Australian applications

The tree-lined entrance to Stadium Australia at the Sydney 2000 Olympics site was an early high profile application of structural soils, in conjunction with permeable paving (Horne 1988; Selvey 1998; Ferguson 2005). The soil was based on the CU-Soil mix, but used smaller (45mm) gravel stones premixed with filler soil (Leake 2003). Care was taken to add only enough filler soil to occupy 50% of the void space. The premixed soil is available in several blends through Benedict Soil and Gravel Pty Ltd in Sydney (http://www.benedict.com.au/soils.html), and has since been used in a number of city centre projects in Sydney.

Structural soils and tree root trench technologies were also pioneered by Lyndal Plant at the City of Brisbane, Queensland. Plant provides an outline of the use of structural soils in Australian cities including Brisbane, Sydney, Melbourne and Hobart (Plant 2002). An early installation was the Albert Street subtropical boulevard in Brisbane, where a root trench opportunity was created by the removal of two parking lanes. The proposed 10 m tall trees were calculated to require at least 8.3 m^3 of soil each, which could not be met with a standard 1.5 m^3 tree pit. A root trench was installed using a 20 mm bluestone structural component with a composite soil media as backfill. This was also used in the Roma Street Parklands and Grey Street Boulevard projects.

Evaluation of structural soils

Initial testing of CU-Soil at Cornell's Urban Horticulture Unit (UHI) indicated favorable results in terms of tree growth, vertical root distribution, and root and shoot elongation (Grabosky *et al.* 1998a; Grabosky *et al.* 2001; Grabosky *et al* .2002). In particular tree roots were observed to grow twice as deep in structural soils as in a standard soil (Grabosky *et al.* 1998a). The progress of hundreds of trees planted in New York State from 1997 has been compared favorably with those planted in standard tree pits (Grabosky *et al.* 2002). Approximately ten years ago structural soil was installed in a plaza in the Vancouver CBD in Canada, and when the trees were removed in 2007 they showed healthy, extensive root systems, and no conflicts with surrounding pavements (Connery 2009).

In the last few years, however, a number of criticisms have been made of structural soils, especially those based on a stone matrix. One of the main criticisms is that they provide proportionally small volumes of growing medium, which is typically less than 30% of total volume (the remaining 70%

comprising inert stones) (Connery 2009). Other criticisms include the need for long term monitoring of tree growth in terms of possible limitations in terms of water, fertility and the ability of larger roots fitting through the voids in the stone matrix (Harris *et al.* 2004; Roberts *et al.* 2006).

In the first edition of their book *Sustainable Landscape Construction,* Thompson and Sorvig (2000) gave qualified support to structural soils as an innovative tree planting practice. However in the 2008 edition they provide a detailed critique of structural soils, especially the Urban Horticulture Institute patented CU-Soil (Thompson & Sorvig 2008). Issues raised include handling and mixing, with the patented soil requiring licensed installers. Having a single specification however does not account for local conditions and one mix may not suit all conditions. Mixing off-site ensures quality control, however the mix may segregate during transportation. On the other hand, mixing on site may not achieve the required specification, and most specifications use weight rather than volume as a measure which is often impractical in the field (Connery 2009). Thompson and Sorvig (2008) also report criticisms by Philip Craul that sand-based mixes are horticulturally superior to, less costly than, and almost as good in structural terms as CU-Soil. While CU-Soil achieves about 95% Proctor density (the standard US highway base course requirement), other structural soil mixes can achieve 85-90%, which is widely accepted in Europe, 85% is also the accepted standard under porous pavements (Ferguson 2005).

Comparative studies

A number of recent studies have compared tree growth in a range of urban soil installations. Kristofferen (1999) compared above and below-ground growth of trees planted in: topsoil; three structural soils; compacted sandy-loam subsoil; compacted gravel; and a sand-humus mix similar to Amsterdam Tree Soil. The topsoil, compacted to 75% of peak bulk density, provided optimum conditions for root growth. The sandy-loam subsoil was compacted to 85% of peak bulk density to represent typical conditions during building construction (Randrup & Dralle 1997). The gravel was compacted to peak bulk density to represent normal pavement base-course. The sand-humus mix was compacted to 80% of peak bulk density as recommended for Amsterdam Tree Soil. Three structural soils were tested with either granite, lava and brick structural components. Root growth two years after planting was severely constricted in the compacted gravel, subsoil and sand-humus mix. Root growth in the three structural soils was similar to, or better than in the topsoil. The height growth of the tree crowns was similarly affected. Reduced root growth in the compacted soils was attributed to poor drainage and frequent water-logging, which also occurred in the sand-humus mix, while reduced root growth in the compacted but well drained gravel was attributed to mechanical impedance.

Another study in 2006 compared five different soil treatments aimed at improving growing conditions under pavements: compacted soil; gravel-soil mix; Stalite (a structural soil); Stalite-soil mix; and non-compacted soil covered with a concrete suspended slab. A variety of growth parameters were measured, and the non-compacted treatment showed greater trunk diameter growth; greater twig growth; higher relative chlorophyll; and greater root growth (Smiley *et al.* 2006). The authors concluded

> *Suspended pavements over non-compacted soils provided the greatest amount of tree growth and health and should be considered when designing urban planting sites for trees* (Smiley *et al.* 2006 p.164).

In 2007 researchers also investigated the different approaches to extending soil volumes implemented in Copenhagen, Denmark in the previous fifteen years (Buhler *et al.* 2007). These comprised: structural load bearing soils; sand based load-bearing soils; trees in conventional tree pits (which vary from 1.5-6 m^2 of surface area averaging 3.2 m^2); and the so-called ‘super planting pits’ (which do not use structural soil, but which provide a large unsealed surface of greater than12 m^2 in combination with deep soil loosening providing at least 15 m^3 of soil per tree). Growth in the conventional pits varied considerably, reflecting local conditions. Alternative methods were found to be at least comparable with traditional methods. Tree growth in the ‘super planting pits’ was found to be superior to all other methods in terms of growth and vitality, and was recommended wherever space for large planting pits with open surfaces was available.

In the United States Xiao and McPherson (2008) have also tested three engineered soils, CU-Soil ((Grabosky *et al.* 2002), Carolina Stalite Soil (Costello & Jones 2003), and Davis Soil (a mix of 75% porous rock and 25% clay loam soil), and found them all effective in removing pollutants from stormwater runoff, and storing runoff below-ground.

6.3.5 Tree pit design

Best arboricultural practice

Tree pits in constrained urban situations, surrounded by hard paved surfaces, require specialized design solutions. However, where possible these should reflect accepted best practice in tree pit design in open planting situations. Current ‘best practices’ based on the biological requirements of trees, have been identified by a number of researchers and practitioners (Craul 1992; Gilman 1997; Watson & Himelick 1997; Craul 1999; Harris *et al.* 2004; Craul & Craul 2006; Balsamo 2008). These requirements can be summarized as follows.

a) Excavate the hole approximately three times larger than the rootball.
b) Avoid vertical pit walls, but rather flare the walls out in a ‘wok’ shape to increase the size of the mulched opening.

c) Tree pit depth should be a little less than rootball height (it is preferable to plant a tree too shallow than too deep, to avoid collar rot).

d) The rootball should be placed on a firm surface to avoid future settling and risk of collar rot.

e) Roughen the tree pit walls if they are smoothed during excavation, to facilitate root penetration.

f) Provide adequate drainage by breaking through any compacted layers, or installing under drainage. As a guide the tree pit can be filled with water and the rate of drainage observed.

g) Backfill with the unamended original soil removed from the tree pit.

h) Slope backfill upwards from the trunk to create a watering bowl.

i) Cover with mulch to the recommended thickness, leaving a space between the trunk and mulch to avoid collar rot.

j) Staking is not considered desirable in terms of developing wind-firm trees, but if required as a de-facto 'tree guard' it should be installed in accordance with current best practice (Harris *et al.* 2004).

Figure 11 illustrates a current best practice tree pit detail.

NOTE:
This figure is included on page 98 of the print copy of the thesis held in the University of Adelaide Library.

Figure 11: Best practice tree pit detail

Source: Metrotrees (2006).

Dimensions and proportions

The shape, as well as the quantity of the soil volume can also influence tree growth (Urban 1996). Traditional tree pits have reflected common 'flower pot' shapes, being much deeper than wide. However such shapes do not provide adequate soil volumes, or reflect the form and extent of root systems (Perry 1982). Tree pits should be shallow and wide rather than deep, the key limiting factor to depth being aeration, with roots not utilizing the soil deeper than 0.6-0.9 m except in excessively well drained soils (Craul 1992). Lateral spread also helps to protect the tree against wind-throw, and Urban (1996) suggests that soil volumes with a radial rather than a linear shape will provide trees with greater structural stability. Craul also recommends a minimum as well as maximum depth for tree pits, of around 0.45-0.5 m, with shallower pits drying out excessively quickly and resulting in less wind-firm trees. Trees in excessively shallow pits may also require some form of sub-surface guying (Craul 1992). Urban also suggests that tree pit volumes should be interconnected, or connected to adjacent soil volumes such as lawns (Urban 1996).

Tree pit drainage and aeration

Tree pits dug in compacted soil may suffer poor drainage, exacerbated by the use of high quality infill (a practice no longer recommended) creating discontinuities between the pit and the surrounding soil, resulting in the ubiquitous 'tea cup effect' in which water collects at the bottom of the pit creating anaerobic conditions (Spirn 1984a). Oxygen deprivation of the root system can result in reduced tree vigor and death (Berrang *et al.* 1985). The rootball of trees planted in pits with a saturated base may also settle lowering the root collar below soil surface level (Craul 1992).

Under-drainage should be installed in tree pits dug in poorly drained soils, typically involving some form of perforated pipe connected to a drainage outlet such as a stormwater pipe. The pipe may be wrapped in geotextile fabric to prevent clogging by silt (Craul 1992). Craul also advises that placing gravel at the bottom of a tree pit does not improve drainage, as the gravel layer acts as a void under dry conditions, and as a water reservoir under saturated conditions effectively reducing the soil volume which could be used to store water under unsaturated conditions (Craul 1992). Vertical aeration pipes are also sometimes installed to aerate or dry out the soil, but their effectiveness is questionable (Craul 1992).

Design of the tree pit surface

The size of the pavement opening and the nature of the tree pit surface also influence tree growth (Gilman 1997). Key considerations include: protection from compaction by pedestrian traffic; and creation of appropriate growing conditions including aeration, water infiltration and nutrient supply. In 1916 Cox recommended a range of tree pit sizes related to planting conditions, from 1.2 m x 2 m x 1.1 m deep, to 1.4 m x 2.4 m x 0.9 m deep (Cox 1916). He also recommended that openings around trunks should be no less than 0.8 m by 0.9 m with brick surfaces, and that planting verges be a minimum width of 1.8 m to 2.4 m and 0.9 m deep.

Options for protection of the tree pit surface include ‘tree grates’ suspended over the tree pit, over a void or gravel-filled space. Tree grates are decorative, but may provide little significant benefit, and may even be harmful to the tree. Grates can damage the tree trunk unless regularly enlarged, which may be neglected. The edge structure supporting the grate, on a compacted base, can also effect root growth. In addition, litter can collect under grates (Urban 2007). Other options include the use of underplantings, or low fencing provided in conjunction with underplantings as in the Golden Mile in Michigan Avenue, Chicago, Illinois (Craul 1992). Porous pavers can provide a trafficable surface while enhancing water infiltration and aeration (Ferguson 2005). Open jointed pavers for instance allow significant amounts of seasonal rainwater infiltration (Kopinga 1985). Organic mulches when correctly applied have many benefits, including elimination of weed competition and the alleopathic effects of grass (Litzow & Pellett 1983). Disadvantages of organic mulch include: high maintenance requirements; tendency to wash away in rain; and susceptibility to scattering, decomposition and compaction. Gravel has a number of advantages as a mulching material: it is load bearing; does not wash away in rain; maintains infiltration; and reduces weed growth. Angular gravel which interlocks is less preferable to scattering. Disadvantages include the use of stones as missiles and the chemical effects of weathering (Roberts *et al.* 2006). Resin bonded gravels have been developed which are porous, and overcome some of the problems of loose gravel (Ferguson 2005). Traditional recommended practice has been to drain pavement surfaces away from tree pits to protect trees from inundation, increases in alkalinity and inflows of oil and other toxicants (Harris *et al.* 2004). Current Water Sensitive Urban Design practices may direct stormwater runoff to tree pits for infiltration and biofiltration purposes, however such systems are often provided with under-drainage to remove excess water (Wettenhall 2006).

6.3.6 Extended rooting space

Shared rooting volumes

A number of authors have recently emphasized the value of creating ‘shared rooting volumes’, either in a much larger planting space containing a group of trees (a ‘tree island’), or by interconnecting tree pits with some form of ‘soil trench’ (Kuhns *et al.* 1985; Patterson 1985; Craul 1992). Urban (1996) suggests that two trees planted in a certain soil volume will grow larger than a single tree with half that volume.

Tree islands

Large common tree planting pits can sometimes be created where space exists in large open verges or medians (Costello *et al.* 2000). Urban suggests creating 'tree islands', by identifying areas where several trees can be planted in a large pit with a shared soil volume (suggested to be 3 m x 7 m or larger). Such tree islands could be strategically located, at perhaps one or two per street block, allowing for the growth of larger trees in the streetscape. These large areas would also allow more effective management of soil compaction, and nutrient, water and oxygen status (Urban *et al.* 1989). According to Edwards and Gale (2004 p.148) from an English perspective

> *Ideally tree pits should be large enough to support an island of trees, as in London's Berkley Square where Plane trees are still surviving and prospering after more than 200 years*.

Linear tree pits

Another option is to create 'linear tree pits' also known as 'continuous trenches', 'root trenches' and 'soil trenches'. These can consist of connecting tree pits by an open verge, or by connecting tree pits beneath pavements (using techniques such as structural soils to support the pavement). Figure 12 illustrates a typical tree root trench installation, with suspended pavement or structural soil options. An early, often cited example is the design of Market Street, Philadelphia, where linear strips were cut into the pavement and replaced with new soil and under-drainage. The design provided increased rooting volume and permeability compared with the separate individual tree pits (Craul 1992). Philip and Timothy Craul also summarize the common elements required for such linear tree pit designs (Craul & Craul 2006). A more recent example is Granville Street Vancouver, Canada where 2.5 m square tree pits have been linked by almost 1.4 km of 1.2 m wide x 0.6 m deep structural soil trenches (Connery 2009).

Figure 12: Typical linear tree root trench

Source: Thompson & Sorvig (2000) p.120.

In Australia Plant (2002) concluded that tree trench installation is an evolving technology which has mainly been applied in high profile sites. While more costly per tree than conventional tree planting, it is considered cost effective in terms of the benefits it delivers. It is, however

> *…but one of many tools to achieve a better balance between infrastructure and tree cover in highly urbanized environments* (Plant 2002 p.4).

Root channels and paths

Another technique cited in the US literature is a 'root path' or 'root channel' which is installed to connect tree pits to areas with larger soil volumes and more favourable growing conditions. 'Root channels' may comprise trenches or pipes filed with soil favourable to root growth, and in Sweden 25 cm pipes (installed 25 cm below the soil surface) have been used as conduits from tree pits, through compacted pavement subsoil to areas of more favourable soil (Costello & Jones 2003). Another design comprises a narrow trench (12 mm wide x 31 mm deep) installed in compacted subgrade, filled with a commercially available plastic strip drain wrapped in geotextile fabric, with the remainder of the space filled with loam topsoil. These are laid out radially from the rootball

(Costello & Jones 2003). This technique remains somewhat experimental and has been less widely adopted than the linear tree pit (Urban 2008).

Tree vaults

Street tree ‘vaults’ are engineered installations which aim to provide trees with improved soil volumes and favourable growing conditions, while protecting them from surrounding soil compaction. In 1981 Jewell (1981) presented and reviewed a number of such designs, in which pavements are suspended over the soil, avoiding compaction, and providing an aeration space between the soil surface and the underside of the suspended pavement. In Pennsylvania Avenue, Washington DC, Willow oaks (*Quercus phellos*) were planted in a 600 mm deep shared rooting space under the footpath (with an aeration and irrigation system), providing a rooting volume of 28.5 m^3 per tree. A similar system was installed in St. Paul, Minnesota, which did not include under-drainage, and with a sand bed separating an aerating gravel layer from the planting soil below. Another variation was installed in the Denver Transit Mall, illustrated in Figure 13, with the complete suspension of the pavement over the rooting soil, supported by the tree pit walls. Such installations represented an early attempt to address the issue of growing trees in compacted and paved urban settings, and while reported to be effective, are also expensive to install and maintain (Craul 1992).

NOTE:
This figure is included on page 104 of the print copy of the thesis held in the University of Adelaide Library.

Figure 13: Denver Transit Mall tree vault

Source: Roberts, Jackson & Smith (2006) p.200.

Root bunkers

Large scale tree vaults known as ‘root bunkers’ have been successfully installed in The Netherlands (van Loon 2006). The first bunkers were developed at Apeldoorn in 1997, with design based on a providing a minimum rooting volume of 40 m^3, with trees expected to last for 80 years. In that 80 year period it is expected that sewerage will be replaced once, paving twice, and adjacent buildings may also be replaced. Trees planted in the bunkers will be unaffected by such developments being essentially ‘underground reserves for trees’. The tree bunker is constructed on a footing, with a cover designed to support the above ground loads and facilities. Under the cover is a water infiltration system connected to mains water or rainwater. Also below the cover is a 10mm gap for air circulation. Trees in the bunkers are protected from surrounding development, and from underground services, so their root systems will not be affected by normal service excavations or construction impacts. In addition, a wider range of tree species can be planted than in conventional tree pits, as the roots do not exert forces on the surrounding paving.

Suspended pavements

An alternative to the use of structural soils is the installation of 'suspended pavement' where the paving is cantilevered over the tree pit or soil trench (Roberts *et al.* 2006). Tree roots can then grow in loose, uncompacted soil, and as the pavement does not contact the soil below, a void can be created which allows water and gaseous exchange. In 1997 Gilman described a method of suspending entire footpaths supported by pilings or angle irons, illustrated in Figure 14. An example in Pennsylvania Avenue, Washington D.C. is cited, in which eight (removable) slabs surrounding the tree opening were supported on pilings (Gilman 1997). In 1989 Urban described a system being tested in Washington D.C., New York and other cities in which a new pavement is poured over a 1 m deep x 1200 mm wide trench filled with loose soil and drainage lines, with a 100 mm gravel cushion between the soil surface and pavement underside, to allow air and water exchange (Urban *et al.* 1989).

NOTE:
This figure is included on page 105 of the print copy of the thesis held in the University of Adelaide Library.

Figure 14: Suspended pavement concept

Source: Hitchmough (1994) p.384

In Brisbane Queensland Plant (2002) used a reinforced concrete slab suspended over a root trench, rather than a structural soil. A void between the slab underside and soil surface allowed aeration between each grated tree site. Capped access points were also provided to allow watering and fertilization. The suspended slab system makes more rooting volume available than with structural soils where the stone matrix occupies up to 60% of the trench volume. Suspended pavements can be seen as a 'second generation' successor to structural soils, overcoming the structural soil limitation of restricted soil volume. Suspended pavements, in the form of cantilevered slabs, however, are limited in the dimensions they are capable of spanning, and are best suited to relatively narrow width root trenches.

Sub-pavement aeration

Direct aeration and water infiltration of the soil may be precluded when engineered concrete slabs are installed on a sand or gravel sub-base. Craul (1992) cites a number of attempted solutions. Flexible perforated pipe was installed below pavement as an irrigation and aeration system in Pennsylvania Avenue, Washington D.C. And at 1600 Pennsylvania Avenue a combined irrigation and aeration system was installed between a double row of American elms (*Ulmus* spp.) in the gravel layer below the pavement, with both ends terminating in junction boxes.

Raised planters

Trees can also be planted in raised planter beds or berms, open to the soil below, increasing accessible soil volumes (Gilman 1997). This may be applicable in situations with soil depth restrictions due to the presence of underground structures or services. Raised planters increase soil volumes, and can be designed to be integrated with public seating. Disadvantages include the need for sufficient width to accommodate framework roots, and the creation of physical and visual obstructions in the streetscape.

Containerized planting

Trees may be planted in containers in situations with adverse soil conditions or limited below ground planting space. Issues with containerized trees include aesthetics and sustainable management. Small containers can create visual clutter, provide only limited shade, and can create a temporary unplanned appearance (Craul 1992). Rather, according to Cervelli (1984 p84.)

> *Trees should be used in an assertive architectural fashion to reinforce and connect the spaces and corridors created by buildings.*

Containerized trees are also subject to inherent problems due to their limited size and stressful planting situations. These include: limited rooting volumes; excessive wetting or drying; nutrient deficiencies; and heat stress (Spomer 1980). Installing containerized trees, therefore, requires detailed consideration of: container size and dimensions; soil specifications; plant species selection; watering regime; and a long term maintenance program and budget.

Cervelli (1984) recommends containers no less than 2.4-3.0 m in diameter, as well as a range of other aesthetic guidelines. Shape should be based on biological as well as aesthetic criteria, with wide, shallow proportions preferred (Urban 1989). Containers deeper than 1200 mm provide wasted rooting volume, while those less than 600 mm will have reduced rooting depth, reduced water holding capacity, and may be more susceptible to wind-throw (Craul 1992). Containerized trees require a soil that is both well drained and with sufficient water holding capacity to sustain tree life between rainfall or irrigation events (Spomer 1980). Craul (1992) provides a number of soil specifications for containerized trees. Preferred tree species include those with good proportions of crown width to height (Rakow 1987). A long term management plan is also required to compensate for limited soil volumes and stressful locations (Lindsey & Bassuck 1991).

Structural cells

In the last five or so years, systems of plastic cells have been developed which provide load bearing support for pavements, while creating a matrix of soil filled voids which can support root growth. These appear to be the 'next generation' in design to extend rooting zones below pavements in highly urbanized settings (Urban 2008). They are an attempt to address the limitations of 'first generation' structural soils, and 'second generation' suspended pavements. Stone based structural soils may have limited rooting volume, in which only 20% or so of the mix is occupied by soil filled voids. Paving on suspended reinforced concrete slabs may require an expensive engineered design, and may be only to span limited distances (although effective for relatively narrow root trenches). Suspended slabs also create an impervious surface over the root trench. Structural cell systems also have the potential to be combined with Water Sensitive Urban Design treatments which can capture and store stormwater runoff. Figure 15 illustrates the use of structural cells to extend the rooting zone below the adjacent pavement.

NOTE:
This figure is included on page 108 of the print copy of the thesis held in the University of Adelaide Library.

Figure 15: Structural cell system concept

Source: Urban (2004) p.19.

Initial applications used plastic cell systems designed for sub-surface water storage, such as the Atlantis system (http://www.atlantiscorp.com.au/) but filling the voids with soil for root growth. In The Netherlands these were known as ‘tree crates’. A system was pioneered in Apeldoorn in 1995 using rainwater infiltration crates (van Loon 2006). These were intended to store stormwater for slow release, but were filled with tree soil when they emptied more quickly than intended. However they were unable to withstand continuous heavy loads so the authorities developed an alternative tree bunker system. In recent years two more advanced load bearing systems have been developed.

In the United States Deeproot Silva Cell has been developed by landscape architect James Urban in partnership with Deep Root (http://www.deeproot.com/) (Urban 2008). It comprises a modular system of glass reinforced polypropylene structural cells, installed in a pit on a compacted base and backfilled with uncompacted soil. Paving on an aggregate base can installed over a geotextile layer placed on top of the grid of cells. The system is designed to meet AASHTO H-20 loading specifications, supporting a truck of 9,000 kg (Connery 2009). In Silva Cell the structural component occupies only 10% of the below ground volume, allowing 90% growing medium, by volume. In Vancouver's 2010 Winter Olympic Village, 2750 square metres of Silva Cell have been incorporated in various locations, at a rate of 24 cubic metre per tree. The cost of such systems can be perceived as a deterrent, with Silva Cells being installed for USD$460 per square metre, compared with structural soils at USD$90 per cubic metre. However the manufacturers claim the system to be cost effective in terms of cost per cubic metre of actual growing medium installed, with the growing medium in structural soils comprising only 20% of the mix. In addition, such systems are advocated as providing enhanced opportunities for providing other ecological services such as treatment of stormwater runoff (Connery 2009).

In Australia Arborgreen (http://arborgreen.com.au/) markets an integrated tree pit system, based on an established European system known as Greenleaf. The system combines root directors, subsurface irrigation and aeration, and RootCell structural cell modules. The structural cell system comprises a dense grid of plastic cells which are load bearing (44 tonnes per square metre if evenly distributed) and provide 90% soil by volume. Auckland City Council in New Zealand has recently tested the structural stability of the tree pit system on adjacent road pavements. The system has been installed in Europe, for example at Wembley Stadium (Arborgreen 2007), and in Australia at Bankstown NSW (Arborgreen 2008), Newcastle NSW (Arborgreen 2007), and Epping NSW (Arborgreen 2009).

Integrated approaches

According to Urban (2007 p.362)

> *Traditional urban designs in which trees are regularly spaced in small openings within paved areas generally result in poor tree performance.*

While uncompacted soil volumes can be installed below paving, this is a costly option and should be considered as a last resort compared with a more flexible approach to planning the street space.

> *Urban designs should have flexible relationships between trees, paving, and planting beds and large areas of open planting soil offer the best opportunity for long-term tree health and lower maintenance costs* (Urban 2007 p.362).

Urban has published a number of 'sidewalk planting options' in *Landscape Architecture Graphic Standards* and elsewhere (Urban 2007 p.362). The four options, presented in Figure 16, comprise the following:

> ***Best option**: planting trees between sidewalks and buildings creates the fewest conflicts between roots and paving by permitting rooting activity on adjacent property. Includes continuous mulched or planted areas and improved soils.*
> ***Acceptable option**: planting between kerbs and sidewalks in a continuous unpaved planting bed provides good soil levels for trees, but contributes to root/pavement conflicts as trees mature. Includes continuous mulched or planted areas and improved soils.*
> ***Difficult design option**: in highly developed areas with parking adjacent to the kerb, planting in long narrow tree openings (width 3 m or more) with a 450 mm wide walk along the kerb accommodates pedestrians exiting cars. Root/paving conflicts are probable. Continuous interconnections of soil from tree to tree are required under the paving.*
> ***Most difficult (and most expensive) design option**: tree openings are undersized for future trunk/root development and severe root/paving conflicts are likely. Openings should be made as large as possible. Footpaths should be made as narrow as possible. Continuous interconnections of soil from tree to tree are required under the paving.*

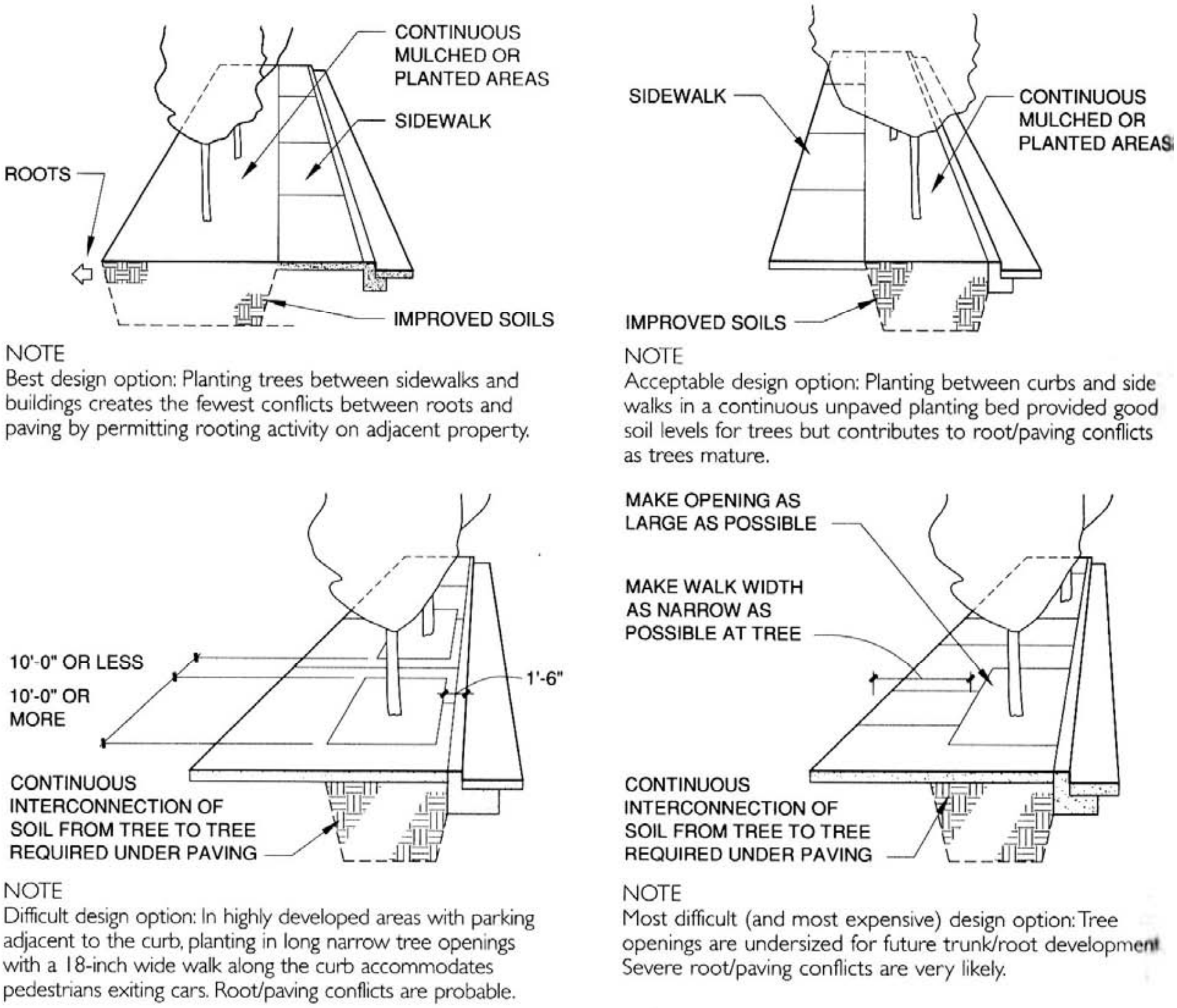

Figure 16: Sidewalk planting options

Source: Urban (2007) p.362.

6.3.7 Conclusion

Traditionally urban street trees have been planted in small tree pits dug in compacted soil, in which the tree roots have been limited to the confines of the pit, and are unable to access the resources necessary for growth. However there is a clear relationship between the size of a tree and the size of its root system and below ground space. Restricted soil volumes have had a number of consequences including dwarfing, declining tree health, and increased tree mortality. Attempts have been made to quantify the relationship between the size and required soil volumes. These have been based on either empirical observations, or calculations of soil volumes required to meet the water demands of the tree. While the results vary widely, it is clear that most urban planting situations provide useable soil volumes well below the optimum, or minimum requirements of the tree.

Attempts have been made to extend the rooting zones of trees in confined urban settings, including extending the rooting zone below surrounding pavements. Options include creating shared rooting volumes in the form of tree islands or linear root trenches connecting individual tree pits. Structural soils are one attempt to meet the conflicting requirements of providing soils below pavements that meet both the load bearing requirements of engineers and the biological requirements of trees. Structural soils comprise a family of different soil types, the most well known being those with a load bearing stone matrix such as CU-Soil. In recent years structural soils have been criticized for a number of reasons including the fact that up to 80% of the mix may comprise inert stones, with only 20% of rootable soil volume. A second generation option for extending rooting zone below pavements comprises suspended pavements in which a concrete slab is cantilevered over a tree pit root trench. An 'emerging' third generation approach comprises the installation of a matrix of load bearing plastic cells, with the soil filled voids comprising up to 90% of the below ground volume. Such approaches are expensive but may be cost effective in confined urban settings where tree planting is mandated. Alternative approaches, such as those outlined by James Urban, begin with the initial design of the street to create the largest volumes of uncovered soil possible.

Table 28 provides a summary of key below ground strategies and practices identified in this section of the thesis.

Table 28: Summary of below ground practices

Strategy	Practice	Comment
Required soil volume calculation	Empirical	Urban chart (Urban 1992)
	Water demand methods	Lindsey and Bassuk (1991)
Soil modification	Cultivation	
	Amendment	
	Mulching	
Soil replacement	Replacement	
Structural soils	Stone based	CU-Soil, Danish
	Porous aggregate based	Carolina Stalite, Arnold, Davis
	Sand based	Amsterdam
	Colloidal based	SPACE
Tree pit design	Best arboricultural practice	
	Proportions	
	Drainage	
	Tree pit surface	Grates, underplanting, mulch, gravel, permeable paving
Extended rooting volumes	Shared volumes	Tree island, linear trench
	Root paths	Root channel, root path
	Suspended pavements	Supports, slabs
	Vault systems	
	Root bunkers	
	Structural cells	
Containerized planting	Above ground containers	Volumes, water, fertility
	Raised planters/podia	
Streetscape design	Open verge by property boundary	
	Open verge by kerb	
	Enlarged tree pits by kerb	
	Confined tree pits by kerb	

6.4 Water management

6.4.1 Introduction

Urban street trees face additional problems to those growing in parks or other open space areas. These include: increased evaporative demands; and restricted water supply (Roberts *et al.* 2006). There are additional atmospheric demands due to: higher temperatures; atmospheric humidity deficits; increased wind speeds and evaporative potential; increased radiation load imposed by surrounding built surfaces. Water supply is usually reduced due to: decreased infiltration and increased runoff from hard surfaces; the low water holding capacity of compacted urban soils; and restricted soil volumes in urban tree pits which limits water availability (Whitlow & Bassuck 1987). Urban street trees will therefore experience more extreme and frequent water deficits. In recent years, in Australia and elsewhere, this has been exacerbated by the effects of drought, water restrictions and climate change (Connellan 2008b). The following sections provide an overview of water management practices for urban trees from a water supply and demand perspective (Whitlow & Bassuck 1987).

6.4.2 Water demand

Natural mechanisms

Transpiration is the mechanism by which water is taken up from the soil and lost to the atmosphere through the stomata in leaves (Roberts *et al.* 2006). Transpiration is a passive process driven by differences in water potential between the soil, the different parts of the tree, and the atmosphere. In simplified terms, the strong cohesive attraction between water molecules creates a continuous chain within the plant, and water molecules lost to the atmosphere through the stomata effectively draw water up through the plant stems and roots and out of the soil, which can be conceptualized as a soil-plant-atmosphere continuum. Most of the water taken up by the tree is used for transpiration, which carries out the important function of cooling the leaf during the evaporation process (Kopinga 1998).

The driving force of transpiration, therefore, is evaporation of water vapour at the leaf surface. The level of evaporation will depend on atmospheric conditions including: solar radiation; air temperatures; humidity; and wind (Whitlow & Bassuck 1987). Water lost to the atmosphere at the stomata can be replaced by water extracted from the soil via the roots; a relationship that can be conceptualized in terms of water 'supply and demand'. Water supply will depend on soil factors such as available moisture which is related to available rooting volume. Water deficits can occur, including short-term deficits even when there is adequate water in the soil, if atmospheric demands exceed the ability of the root system to meet the demand (Hinckley *et al.* 1978). Such deficits can be partially alleviated by closing the stomata to reduce water loss, but this also limits the entry of carbon dioxide which is crucial to photosynthesis and plant growth.

Leaves need to dissipate very large amounts of heat, as the heat load on a leaf in direct sunlight is extremely high. Heat is removed in several ways: by re-radiating heat in the infrared; by dissipating heat to the surrounding atmosphere by convection and conduction (if the surrounding air temperature is lower than the leaf temperature); and by the evaporative process which requires energy and removes heat from the leaf (Roberts *et al.* 2006). The principal weather factors affecting the rate of evaporation from the leaf surface are: radiation; air temperature; humidity; and wind speed.

Urban microclimate

Compared with the forest, urban microclimates are characterized by significantly higher temperatures, higher wind speeds and lower net rainfall inputs (Miller 1980). The predominance of artificial surfaces substantially modify the surface energy budget (Quattrochi & Ridd 1994). The built environment of cities has been described as a

> *…harsh montage of reflective and absorptive surfaces, including roads, buildings, pavements and cars* (Lindsey & Bassuk 1992 p.25).

Urban centres typically exhibit higher temperatures than surrounding areas, a phenomenon known as the ‘urban heat island effect’ (Bornstein 1968). The urban heat island effect results from the storage and re-radiation of heat by building materials, and from burning fuel for heating and transportation. Reduced tree cover in many urban areas also leads to a reduction in transpirational cooling and shading of surfaces compared to rural areas (Federer 1976).

While the general urban heat island effect is well documented, the micro-energy exchanges between trees and adjacent built surfaces are less easily categorized (Miller 1980). At a local level, tree canopies experience not just an increased radiation load due to reflection and re-radiation from adjacent surfaces, but also daily variations in energy input. Metallic structures such as cars heat and cool quickly, however concrete and masonry surfaces and structures continue to re-radiate heat into the evening, creating a different environment to rural settings.

The paved asphalt and concrete surfaces that predominate in cities: create higher surface temperatures; and reduce soil evaporation that may normally cool the soil surface (Miller 1980). Trees in paved areas have been shown to increase rates of transpiration compared with turf areas, however water demand also varied with tree species (Kjelgren & Montague 1998). Paving induced temperature increases can also effect trees in other ways, and root zone temperatures have been shown to be significantly higher in urban sites characterized by asphalt and concrete, than in suburban or woodland sites (Graves & Dana 1987). By shading ground surfaces, trees can reduce the amount of radiation reaching, being absorbed, and being re-radiated from paved surfaces (Roberts *et al.* 2006).

Cars are some of the hottest objects in the city in terms of radiating heat, and the combination of high temperatures and proximity to tree canopies makes car roofs potentially damaging to street tree leaf functions (Whitlow & Bassuck 1987).Evapotranspiration and water demand can also be increased by lower humidity and increased wind speeds caused by wind tunnel effects in cities, and wind speeds between tall buildings can match those on exposed sites (Bradshaw *et al.* 1995).

6.4.3 Water supply

Urban water cycle

Trees play a significant role in the natural water cycle. In urban areas the natural water cycle is significantly modified, however trees can still play an important role. Tree canopies intercept rainfall, with solitary trees intercepting more rainfall than similarly sized trees in a forest situation. However the typical scenario of a small number of widely spaced street trees results in lower rates of rainfall interception per unit of ground area (Johnson, Bell & Stanley 1975). Rainfall that is not intercepted typically falls on extensive impermeable surfaces, resulting in increased runoff and reduced infiltration rates. Infiltration rates have been measured through a number of common surfaces, being greatest in open, freely drained loam soils, slow to non-existent through surfaces such as compacted soil and asphalt, but greater in porous pavements, especially those allowing infiltration through the gaps between pavers than through the paver material itself (Roberts *et al.* 2006). Urban runoff is also directed away from the area where soil moisture recharge is most needed, below the tree canopy, via. gutters and stormwater drains (Bernatzky 1983). At the same time the tree's access to groundwater or subsurface drainage is usually eliminated (Whitlow & Bassuck 1987).

Water restrictions

Street trees also benefit directly and indirectly from the irrigation of public and private landscapes, and landscape irrigation can be a large component of urban water use. Authorities may initiate water conservation programs in response to drought, water quality issues and groundwater depletion (Spinti *et al.* 2004). However such programs are often implemented without regard to the water requirements of trees and other plants (Stabler & Martin 2000). Australia has suffered drought conditions in a number of regions since 1996 with the current drought also being the hottest. Drought and declining dam levels have resulted in prolonged water restrictions in all Australian capital cities except Darwin. This includes Canberra, Melbourne and Adelaide from 2002, Sydney 2003, Brisbane 2005 and Perth since 2002 (first in 1996 and in 2007 restrictions were imposed on bore water irrigation for gardens (Fam *et al.* 2008). In all States these restrictions impose limitations on watering both public and private landscapes. And unlike previous short term restrictions, the current ones have been imposed for a prolonged period (Fam *et al.* 2008). Drought and water restrictions in the last decade have placed stresses on urban trees in Australian cities, with reports of the death of mature trees. Such premature tree loss represents the waste of a significant community resource (Connellan 2008a). Mature trees deliver significant benefits including amelioration of urban heat island effects through shading of surfaces and atmospheric cooling through evapotranspiration (McPherson 1994b). Restrictions on the watering of urban trees and green spaces needs to be evaluated in terms of the costs of watering versus the benefits generated, such as reductions in energy costs through shading (Fam *et al.* 2008). According to Connellan (2008a) future water supply in urban areas is likely to continue to be constrained by a number of factors, with implications for urban tree managers.

Soil water

According to Connellan (2008 p.5)

> *The single most important water factor influencing long term survival of a tree is the size of the available soil moisture reservoir.*

This is determined by soil root volume which relates to the extent of the root system. Storage volume can be described as V = AR x d x W litres, where AR is Root Zone Area (m^2), d is depth (m) and W is Available Water (mm per m depth of soil) (Connellan 2008a). In an unrestricted setting such as a park, roots can extend into the surrounding soil enabling a tree to survive a range of climatic conditions. A tree planted in the limited confines of a container, however, will require supplementary watering. A street tree lies between these two extremes. The extent of the root system is generally not known; root extension is limited by kerbing, road pavements, building footings and underground services; and soil water storage may be in the range of only 5,000 litres, representing only 25 days storage at 200 litres per day (Connellan 2008a).

It should be noted however that a street tree pit is not a closed system, and street trees may also obtain water from a range of sources including natural rainfall, leaking pipes, stormwater outlets, pavement infiltration and irrigation.

> *It is evident from casual observation that most large and established trees in paved areas must have access to water from beyond the normal tree pit to support their canopies* (Edwards & Gale 2004 p.111).

Species such as *Platanus x acerfolia* (London Plane) are often successful in paved urban situations because their root system tolerates low soil oxygen levels better than most, allowing the roots to escape from tree pit and gain access to soil moisture elsewhere (Edwards & Gale 2004). Smith *et al*. (2001b) observed different tolences to inundation in different tree species with *Corymbia maculata* (Spotted Gum) and *Platanus x orientalis* (Oriental plane) able to initiate new root growth in waterlogged conditions, while *Platanus x acerfolia* (London plane) and *Lophostomen confertus* (Brush box) were not.

Connellan (2008a) notes that the trees most at risk from water-stress in urban areas are those with limited soil volumes, not suited to the local climate, with ineffective utilization of existing rainfall and irrigation (including impervious surrounding surfaces), and in hostile soil situations including compaction (a critical factor which reduces infiltration rates and water storage capacity).

6.4.4 Predicting street tree water use

Methods of predicting street tree water use range from simple empirically-derived correction factors applied to pan evaporation methods, to complex data-intensive models of the energy and water balance of tree canopies (Roberts *et al.* 2006).Pan evaporation measures are commonly adjusted using crop indices or forestry correction factors adjusted for urban settings (Harris 1998; Kopinga 1998). Knox (1989) found that combining pan evaporation estimates with derived growth indices gave a reliable prediction of tree water use. Lindsey and Bassuk (1992) illustrate a simple method for predicting water use derived from projected canopy area (m^2), leaf area index, and open water estimates of evaporation. Estimated daily evaporation is then adjusted for a correction factor (accounting for the differences between the evaporation from the same areas of open water and leaf surface) to give daily tree water use (litres). Their study showed that for a range of amenity tree species, 85% of the variability of water use could be accounted for if one had both tree canopy area and evaporation data. Kopinga (1998) reviewed similar studies in The Netherlands and found that 86-90% of variability in tree transpiration rates could be accounted for by multiplying pan evaporation by leaf area index.

Historically, attempts to develop more complex models of transpiration have focused on simulating water use in simple, uniform and closed plant communities (Roberts *et al.* 2006). The heterogeneity of the urban environment however has necessitated a focus on the individual tree crown (Vrecenak & Herrington 1984; Wang & Jarvis 1990; Kjelgren & Montague 1998). This approach however requires accurate measurement of net radiation balance in three dimensions (Green 1993).The relative complexity and amount of data required to run such models limits their practicality at present (Roberts *et al.* 2006). However such modeling of water use by a single tree canopy may help in addressing problems of water supply and demand, and in developing irrigation strategies (Vrecenak & Herrington 1984).

In Australia Connellan (2008a) developed a guide to the water requirements of trees in Melbourne, based on the calculation of daily water use as a function of crown area (CA), leaf area index (LAI), crop factor F) and evaporation rate (EA). Daily Water Use = CA x LAI x F x EA litres per day, and these calculations are set out in Table 29.

Table 29: Weekly water use rates of selected trees in Melbourne

NOTE:
This table is included on page 118 of the print copy of the thesis held in the University of Adelaide Library.

Source: Connellan (2008a) p.4.

Water budgets

A water budget can be written for the root zone of a street tree which considers all water sources and outlets for water loss (Roberts *et al.* 2006). In the absence of irrigation the sole water source will be precipitation (P). Water will be lost through evaporation (E), drainage from the root zone (D) and runoff from ground surfaces (R). Evaporation has three components: transpiration from the tree (Et); evapotranspiration from the soil and understorey vegetation (Es); and evaporation of rainfall intercepted by the tree crown (Ei). The annual water budget for a street tree would therefore be P = Et+Es+Ei+D+R. Changes in water stored in the soil do not appear in the budget as the variation over a year is assumed to sum to zero. A water budget provides a means of assessing whether water management for a tree is adequate and developing strategies such as reducing surface evaporation through mulching, reducing surface runoff with permeable paving, and reducing soil drainage through amendment of soils with low water holding capacity (Lindsey & Bassuck 1991; Kopinga 1998; Brady & Weil 1999; Roberts *et al.* 2006).

6.4.5 Water management practices

Overview

Connellan notes a number of implications for urban tree managers arising from the continuation of urban water restrictions (Connellan 2008a). These include

- A greater focus on selecting appropriate tree species for the locality.
- The need to apply Water Sensitive Urban Design principles more broadly to achieve greater use of stormwater resources.
- Increased use of treated water, requiring consideration of water quality and compatibility with different tree species.
- The need to implement sound procedures and practices to ensure greater success in tree establishment.
- The use of more efficient watering techniques, and compliance with water authority guidelines; and greater accountability for landscape water use, with tree watering being incorporated into water management plans.

Species selection

Tree species selection to suit local soils, climate and microclimate is widely seen as a key to sustainable horticulture (Connellan 2008a). In Australia the TREENET organization (http://www.treenet.com.au/) trials new street tree species and shares knowledge through its membership network (Johnson 2007).

Water Sensitive Urban Design (WSUD)

WSUD practices have a range of water related objectives, but they can also assist in providing adequate water to urban trees by enhancing rainfall infiltration in the soil surrounding the tree. Trees need to draw large amounts of water from the soil water reservoir, which also needs to be replenished with rainfall, or irrigation will be required. However not all the rain that falls is available to the tree. Some is intercepted by the canopy and re-evaporated, and some will be lost in stormwater runoff to drainage systems. Some will not be of benefit to the tree if the soil water storage is at field capacity and the rain does not add to the soil water reservoir. Effective rainfall, a measure of the rain that provides a net addition to the soil moisture in the tree's root zone, may only be 50% of total rainfall. For example a 10 m high tree with a 5 m diameter canopy, and a Leaf Area Index of 3.0 could be expected to transpire 40,000-50,000 litres of water per year at a locality with 1100 mm annual evaporation. With 50% effective rainfall this will require approximately 150 m^2 of ground surface catchment to deliver 45,000 litres annually with 600 mm rainfall (Connellan 2008a). A tree may therefore need a catchment area extending well beyond its root zone. WSUD practices such as permeable paving encourage infiltration into the soil (Ferguson 2005). Other WSUD initiatives such as stormwater harvesting and biofiltration systems can redirect stormwater runoff to the tree's root zone (Wettenhall 2006).

Planting and establishment practices

Balsamo (2008) provides an overview of water efficient tree planting and establishment practices. Water management strategies for newly established urban trees include: maintaining adequate moisture; watering effectively so that water reaches the root system, where it is needed; encouraging extension of the root system; removing competition from around the tree; and mulching (although excessive mulching may intercept rainfall and irrigation water) (Connellan 2008a).Watering innovations trialed in recent years include: slow release water storage devices; water absorbing gels and powders (of most benefit in sandy soils); wetting agents to increase watering effectiveness; water injection tools; drip rings; subsurface irrigation; and 400-500 litre road barriers acting as large water storage devices (Connellan 2008a; Handreck 2008). The City of Melbourne has a large stock of historic mature trees in its high profile parks and boulevards which have suffered in the past ten years of drought. In 2007 a number of watering techniques were investigated. A range of watering well products and a watering trench were installed, with the gravel filled watering trench performing best. This comprised a 1.2 m long by 300mm wide by 300mm deep trench filled with free draining gravel, with water delivered to the trench by an irrigation bubbler (Connellan 2008b).

Soil additives

In recent years the TerraCottem product has been widely applied in tree planting by Australian local government authorities. TerraCottem (http://terracottem.com.au) is a proprietary mix of hydro absorbent copolymers which absorb and store water. The polymer granules absorb water and swell into a gel like substance, and each polymer can store many times its weight in water. The product also contains fertilizers and a carrier material of volcanic pyroplastic rock. TerraCottem claims to reduce irrigation frequency by 50% by absorbing water normally lost through evaporation and leaching. It is promoted as being especially suited to sandy soils, and is applied to the tree pit prior to planting. TerraCottem has carried out field evaluation surveys of product effectiveness as a result of applications at different sites by local Councils.

6.4.6 Tree pit design practices

Required soil volumes

Unless alternative sources are available, the water needs of a tree must be met by the soil water reservoir, including during extended dry periods without rainfall. Key questions that need to be asked are:

- How much water needs to be stored in the root zone to meet the needs of a specific tree? (which depends on species, leaf area and climate) and
- How much water can be stored in the root zone? (a function of soil type, structure and volume accessible to tree roots).

Couenberg (1998) has estimated the required rootable soil volume for new tree plantings based on the water budget for the root zone during the growing season. In an alternative approach, the volume of the tree pit is estimated as the soil volume necessary to store sufficient water to meet the demands of the tree over an interval equal to or longer than 90% of dry periods. The method assumes complete recharge of soil water storage at the end of each dry spell (Lindsey & Bassuck 1991; Lindsey & Bassuk 1992).

Tree pit design

In 2007 a study was undertaken of the soil-water dynamics of one hundred street tree pits in Denmark (Nielson *et al.* 2007). It was discovered that a large proportion of precipitation never reaches the soil matrix of tree pits due to interception by tree canopies, buildings and mulch. The authors suggested extending tree pits beyond the canopy drip line to increase infiltration. They also found that water retention capacity of the tree pits was often poor, with high water loss immediately after precipitation or irrigation, and recommended that this could be improved with the addition of clay granules. It was also suggested that a series of linked planting pits may maintain more homogeneous water retention and better long term tree development.

Tree pit surface

It is important that the soil at the surface of the tree pit remain uncompacted, as this may be the only point where water enters, and compaction will reduce infiltration or stop it completely (Roberts *et al.* 2006). Strategies to reduce compaction include: barriers to foot traffic; permeable trafficable surfaces; soil treatments with organic matter; and mulching (Connellan 2008a). Mulching, if properly applied, also reduces soil moisture evaporation and is of particular value during tree establishment (Greenly & Rakow 1995; Montague *et al.* 2007).

6.4.7 Conclusion

Urban street trees face additional challenges compared to trees planted in open situations such as parks, including increased evaporative demands and restricted water supply. Street tree water management can be conceptualized in terms of a water supply and demand model. Water demand is a function of the transpiration mechanism which is influenced by a range of climatic factors. The urban climate and microclimate, including the urban heat island effect, makes high evaporative demands on trees. The natural water cycle is also highly modified in urban areas and street trees must often survive with a restricted water supply. This is exacerbated by the long term water restrictions being imposed in most Australian cities in response to drought and climate change. Water management for urban street trees is based on the concept of providing an adequate soil moisture reservoir to meet the year long needs of the tree including extended periods without rainfall. Practices to meet the water demands of trees include more effective water management practices for both new and mature trees, and improved tree pit designs that provide appropriate soil volumes and enhanced infiltration. Table 30 provides a summary of key water management strategies and practices identified in this section of the thesis.

Table 30: Summary of water management practices

Strategy	Practice	Comment
Water management	Species selection	
	Planting practices	Watering berm/well. Mulching
	Establishment practices	
	Watering innovations	Additives, subsurface irrigation
	Mature tree watering	Road barrier, watering well/trench
	Alternative water sources	Recycled water (quality)
	WSUD practices	Porous paving, stormwater harvesting
	Water management plans	
Tree pit design	Required soil volumes	Calculations
	Increasing volumes	
	Linked pits	
	Tree pit surface	Compaction reduction, mulching

7 Review of practices to reduce infrastructure conflicts

7.1 Introduction

As well as creating space and the resources to produce healthy trees, street tree managers must also manage conflicts between trees and the surrounding urban infrastructure, including hardscapes, buildings, and services. Street tree managers and infrastructure providers may sometimes have conflicting objectives.

> *Arboriculturists and landscape architects are interested in the development of healthy, vigorous trees; their aims can often conflict with groups providing and maintaining services in the urban environment, whose only interest in trees is generally in preventing them from interfering with service maintenance and function* (Edwards & Gale 2004 p.151).

Tree managers are often faced with the well-known dilemma: when the infrastructure succeeds the tree fails, and when the tree succeeds the infrastructure fails.

> *Such is the dilemma of trees in urban areas. On the one hand, arborists endeavor to overcome poor soil conditions and limited space in pavement to ensure successful establishment and growth (they are not called "tree pits" without reason). On the other hand, good tree growth can cause problems to the infrastructure by lifting and displacing sidewalks and curbs* (Harris *et al.* 2004 p.222).

In the past, approaches to managing such conflicts have usually been tree-based, involving remedial practices such as root pruning or tree removal, or preventative measures such as prohibitions on tree planting or species choice. Arborists argue that it is inappropriate to blame the tree when the conflict is equally a consequence of inadequate infrastructure design, and that improved design could accommodate both infrastructure function and trees.

> *However it must be stressed that although tree roots are blamed for cracking concrete and invading sewer lines, it is equally valid to point out that these structures fail because they have not been properly engineered to function in a landscape that contains growing trees and their roots. Unfortunately the main approach in too many cities has been to remove trees rather than find ways to redesign structures to be compatible with trees* (Ferrini & Fini 2009 p.17).

The following chapter provides a review of literature on tree/infrastructure conflicts including hardscapes, buildings and underground services.

7.2 Hardscape conflicts

7.2.1 Introduction

Hardscape is the term applied to the hard engineered components of streetscapes including road pavements, footpaths, kerbs and water tables (Costello *et al.* 2000). The terminology for different hardscape components varies between different countries, as shown in Table 31.

Table 31: Hardscape terminology

Australia	United States
Road carriageway, pavement	Road carriageway, pavement
Water table, channel	Gutter
Kerb	Curb
Verge, nature strip	Verge, tree lawn, streetscape
Footpath	Sidewalk, pavement, right of way
Tree pit	Tree well, cut-out
Protuberance, buidout, blister	Popout, bumpout
Source: Various sources in the literature.	

Damage to hardscape due to interactions with tree roots is a common problem, especially in confined urban settings. However such damage is difficult to predict due to the unique nature of each planting situation. It is a major concern to engineers and asset managers for a number of reasons including: repair and replacement costs; and pubic liability issues such as trip hazards. However hardscape damage is also an issue of concern to arborists for different reasons: damage to trees during hardscape repair and replacement; and giving trees a bad reputation resulting in restrictions, and even prohibitions, on future tree planting (Roberts *et al.* 2006)

7.2.2 Damage mechanisms

Trees can cause both direct and indirect damage to hardscape. Indirect damage is caused by the effects of tree roots on soil moisture levels, especially in expansive clays (Taylor *et al.* 1966). (The following section 7.3 on building conflicts for a more detailed discussion of indirect damage mechanisms.) Direct damage is caused by the mechanical impacts of tree roots on hardscape.

Direct damage

The probability of a root displacing or damaging an object depends on the ability of the structure to resist the forces exerted by the roots. MacLeod and Cram (1996) measured the forces exerted by roots and found direct damage to be limited to lightly loaded structures such as pavements and low walls. Large trees may damage larger walls depending on their structural integrity. Roots can also form calluses that increase contact with hardscape. Wind loading on trees can also be transmitted to structures via the root system (Roberts *et al.* 2006).

Soil conditions

Direct damage also appears to be less in soils that can deform as the root grows, with the most damage in compacted soils, the most common situation in urban streets where paving is laid on a mechanically compacted base or sub-base (Day 1991). Root proliferation itself is typically restricted in compacted soils, due to mechanical impedance, and water and oxygen status. However one authority reports that tree roots may penetrate road bases with extreme levels of compaction (DETR 1999). Soil compaction is also thought to induce changes in the balance of growth hormones in woody plants, and it has speculated that this may be implicated in the radial enlargement of impeded roots (Kays *et al.* 1974). However the physiology of tree roots growing in impeded urban conditions is still not well understood (Atwell 1993). It has also been found that pavement distortions can occur irrespective of soil conditions when tree roots are growing near the surface (Hamilton 1984a).

Tree damage to hardscape is often attributed to the ‘shallow rooting’ habits of some trees. In fact most trees exhibit some surface rooting (Syndor *et al.* 2000). Roots tend to grow downwards (geotropism), away from light (negative phototropism) and proliferate in optimum conditions of water, aeration and nutrients (Harris *et al.* 2004). It is a misconception to say that roots grow ‘towards’ water, rather they will explore all of the surrounding soil, and proliferate where water is present. The balance of these responses may result in shallow growing roots exploiting the surface levels where soil water, oxygen, nutrient and temperature conditions are often most favourable (Nicoll & Coutts 1997). Surface soils usually offer the best environment for root growth, with pore space and oxygen decreasing with depth (Perry 1982). Oxygen is a key limiting factor, with lack of oxygen reducing root growth, which may halt completely below 10% of oxygen in the air spaces (Hamilton 1984a; Kopinga 1993). Compacted and poorly aerated soils with excess water have been associated with shallow rooting systems and pavement damage (Kopinga 1993; Syndor *et al.* 2000; Harris *et al.* 2004). However others have been unable to link soil factors directly to pavement damage (Costello *et al.* 2000).

Contrary to popular belief, the environment beneath paving is often very favourable to root growth and proliferation, due to the absence of light, and favorable oxygen and moisture conditions (Day 1991; Kopinga 1993; Wagar & Franklin 1994). Soils below impervious pavements lose little water to the atmosphere through evaporation (Kopinga 1993). A number of studies have shown that, during summer months, average temperatures below paved surfaces will be higher than in the adjacent open soil (Halverson & Heisler 1981). Soil temperatures (and diurnal variations) will be determined by a number of factors including albedo (reflectivity), conductivity and thickness of the paving material. Roots will often colonize the resource rich zone between the paving and the compacted base, and radial expansion of the roots may lead to displacement of the paving.

Street trees also typically suffer from limited rooting volumes, and trees in pits dug in compacted soil may have difficulty penetrating the surrounding soil. In fact they may resemble large potted plants (Duryea & Malavisi 1993). Kopinga concludes that much damage to surrounding hardscape is caused by tree roots ‘searching’ for more favourable conditions beyond the tree pit (Kopinga 1993).

Damage without roots

It is also important to note that pavement damage can also occur in the absence of tree roots. Failure rates of footpaths in Cincinnati Ohio were observed to be the same with or without trees (Syndor *et al.* 2000). In addition roots may develop under pre-existing cracks which have lead to enhanced soil aeration (D'Amato *et al.* 2002a). Failures not associated with tree roots may be caused by construction practices or environmental conditions. Some pavement construction methods may be more susceptible to tree root damage, for example asphalt versus unit pavers laid on sand (Wong *et al.* 1988; Syndor *et al.* 2000). Pavement failure is also a function of the age of the asset, and in one study pavement failure was observed to be most likely when pavements were over 20 years old, beyond the actual service life of the pavement (Syndor *et al.* 2000).

Zone of rapid taper

Hardscape damage is most likely in the zone around the base of the tree where expansion of the trunk and the major structural roots is greatest (Roberts *et al.* 2006). In young trees the main form of root growth is by elongation into the surrounding soil. As the tree matures the trunk thickens and is supported by an enlarged framework root. Secondary thickening of the framework roots occurs, with each growth ring increasing root diameter and exerting forces on the underside of the pavement (Nicoll & Armstrong 1997). Wagar and Baker (1983) observed that root damage to hardscape was greatest close to the trunk, with roots forming buttresses against the trunk. Hamilton suggests that buttress formation may also be linked to shallow rooting habit due to raised soil temperatures and humidity below pavements (Hamilton 1984a). Pavement damage is therefore linked to distance from the tree trunk, and in one study trees in planting strips narrower than three metres were found to have caused more damage than those in wider strips (Wong *et al.* 1988). The extent of thickening at a tree’s base (buttress and root flare) can be measured for an individual tree, by comparing diameter at ground level (DGL) with diameter above flare and buttress (DAFB) to give the trunk diameter ratio (TDR), a measure of potential to cause hardscape damage (Costello & Jones 2003). Urban (2007) describes the possible impacts on hardscape of trunk flare and also the ‘zone of rapid taper’ extending about two metres around the base of the tree. Figure 17 illustrates the zone of rapid taper concept.

NOTE:
This figure is included on page 127 of the print copy of the thesis held in the University of Adelaide Library.

Figure 17: Zone of rapid taper

Source: Urban (2008) p.264.

Tree species

Systematic research into interactions between the roots of different tree species and pavements is limited, and is often based on empirical observation. Root examinations are difficult and may take years to complete. Of the species that have been examined, only limited data have been obtained. There may be considerable variation in root characteristics within species, and the root environment is often a significant determinant of root characteristics (Costello & Jones 2003). 'Shallow' and 'deep' rooting habits are usually stressed, however root morphology is very variable and deep rooted forest trees may become shallow rooted urban trees in shallow soils.

Differences that have been recorded between species include: direction (lateral or vertical) of root growth (Costello *et al.* 1997; Nicoll 2002; D'Amato *et al.* 2002a); and mass of the root system (Wagar 1985; Peper 1998; Peper & Mori 1999a). Shallow and deep rooted individuals within the same species have been observed (Burger 2000). Studies by Smith *et al.* (2001a, 2001b) identified differences in response to soil compaction and inundation in a number of Australian and exotic tree species. A number of studies have also related tree species and actual pavement damage including studies in the United States (Wagar & Barker 1983; Lesser 2001; D'Amato *et al.* 2002a); tropical Mexico and Puerto Rico (Francis *et al.* 1996); and the United Kingdom (Wong *et al.* 1988). Some tree species appear to be more involved with pavement damage than others (Ferrini & Fini 2009). This has led to the preparation of tree lists of desirable and undesirable species (Wagar & Franklin 1994; Rindels 1995; Harris *et al.* 2004). However Coder (1998) argues that arborists have become overly reliant on such 'good' and 'bad' species lists, while ignoring

> *… physical forces of tree biological colonization and survival, coupled with systematic design and material flaws in infrastructure that confound tree root growth control* (Harris *et al.* 2004 p.228).

Burger and Prager (Burger 2000; Burger & Prager 2008) have investigated genetic differences in tree species in terms of root depth and orientation to determine if such characteristics could be maintained through vegetative propagation techniques. According to Nicoll and Coutts (1997 P.77)

> *… it should be possible to identify species, and to select trees within species, which allocate root biomass between a large number of structural roots…*

Extent of the problem

Tree root damage to hardscape has been reported as a common problem in the United States where most research has been done (Hamilton 1984a; Stankovich 1990; Bearnhardt & Swiecki 1993; Sealana and Associates 1994). There have been fewer comparable studies in the United Kingdom (Wong *et al.* 1988; Nicoll & Coutts 1997). Hardscape damage has been documented as a major expense in many cities. In the US this includes cities in California state (McPherson & Peper 2000), and in Milwaukee (Hauer *et al.* 1994). In the UK, Manchester (Wong *et al.* 1988), and in parts of Canada (Rajani 2002). A number of US studies identified the total costs including direct repair, legal and administrative costs (Hamilton *et al.* 1975; Wagar 1985; Sealana and Associates 1994; McPherson & Peper 1995; McPherson & Peper 2000). Management of risk and public liability, including 'slip and trip' hazards, has become a major consideration in pavement design and construction. In the UK more damage to asphalt rather than concrete pavers was found, however displaced pavers created a greater threat to pedestrian safety (Wong *et al.* 1988). In South Australia a survey of 33 local councils found that the main contributor to personal injury by street trees was tripping due to pavement damage, followed by blocked sight-lines and litter/slippery paths. The main cause of property damage by street trees was displacement of kerbs, paths and roadways, followed by root invasion of pipes and drains. The main factor effecting dissatisfaction with existing street trees was infrastructure damage (Lawry & Gardner 2001).

7.2.3 Strategies to reduce conflicts

The International Society of Arboriculture has advanced understanding of tree-infrastructure conflicts through the publication of the proceedings of the three International Workshops on Tree Root Development in Urban Soils, as *The Landscape Below Ground*, held in the United States in

1994, 1998 and 2009 (Watson & Neely 1994;Neely & Watson 1998; Watson *et al.* 2009). In 1998 Coder summarized the relationships between tree roots, soils and infrastructure in a paper *Root growth control: managing perceptions and realities*. He emphasized that much infrastructure is

> *…poorly designed and not built to withstand natural processes over time* (Coder 1998 p.51).

However infrastructure managers tend to blame trees for the damage

> *To infrastructure managers, blame for failures are directed elsewhere-in the case considered here to trees. Tree professionals are prone to accept this blame and to damage trees to fit them into faulty design, engineering and maintenance concepts* (Coder 1998 p.51).

Coder identified eight primary forms of root growth control, shown in Table 32, with associated root control tools and techniques. Each attempts to control resource availability, to control resource volume (space) or destroy or redirect root colonization.

Table 32: Root growth control techniques (Coder 1998).

NOTE:
This table is included on page 129 of the print copy of the thesis held in the University of Adelaide Library.

Source: Adapted from Coder (1998).

Coder (1998 p.56) saw 'intelligent development' as the preferred means of

> *…maximizing a tree's, and tree owner's quality of life over the long run.*

On the other hand 'avoidance' (avoiding problems by maximizing the separation of trees and infrastructure) was seen as

> *…probably the most ecological distasteful and socially unacceptable of all forms* (Coder 1998 p.56).

Another symposium in 2000 at the University of California, Davis, highlighted the current state of knowledge concerning conflicts between tree roots and infrastructure. The Western Chapter of the International Society of Arboriculture (WCISA) published the symposium proceedings, *Strategies to Reduce Infrastructure Damage by Tree Roots : Proceedings of a Symposium for Researchers and Practitioners*, containing over one hundred strategies (Costello *et al.* 2000). This provided the basis for the publication of *Reducing Infrastructure Damage by Tree Roots: A Compendium of Strategies*, intended as a resource for practitioners who address conflicts between tree roots and infrastructure (Costello & Jones 2003). As shown in Table 33 strategies for reducing infrastructure damage potential were divided into three groups: tree-based strategies; infrastructure-based strategies; and root-zone based strategies. Strategies could be either preventative, remedial or both.

Table 33: Strategies to reduce infrastructure damage potential

NOTE:
This table is included on page 130 of the print copy of the thesis held in the University of Adelaide Library.

Source: Costello, McPherson, Burger et al (2000) p.5.

Tree-based strategies include selection of less damaging species, and root pruning. Infrastructure-based strategies include: design approaches that increase tree space or reduce proximity to infrastructure; and material-based alternatives which increase the strength or flexibility of pavements. Rootzone-based approaches include systems to direct roots away from infrastructure. Some practices, such as root barriers and structural soils, have received considerable attention in recent years, while others such as soil water management to control root growth have received less. Lawry (2005b) restates these strategies from an Australian perspective, listing seven strategies in order of preference. Theses are: tree literate design; root baiting; root exclusion; barriers; root pruning; species selection; and exclusion zones. Lawry criticizes the response of asset managers to 'blame the tree' and to list and prohibit the 'worst offenders' in statutory regulations.

> *Unfortunately these regulations if applied to the letter would severely reduce the options for creating a rich and diverse urban forest, a totally unacceptable and unnecessary outcome* (Lawry 2005b p.398).

Therefore

> *We just need to stop blaming the tree and start designing for their needs, as well as those of the built environment* (Lawry 2005b p.399).

Improved knowledge of tree root and soil interactions will hopefully lead the the better management of urban soils to help prevent unwanted root colonization around infrastructure (Yau 1991; Moore 1994; Smith 1997). Moore (1994) proposed a number of simple management practices to limit root damage to hard structures and services, summarized in Table 34.

Table 34: Management practices to limit root damage

NOTE:
This table is included on page 131 of the print copy of the thesis held in the University of Adelaide Library.

Source: Moore (1994).

7.2.4 Tree based practices-species selection

Appropriate tree species selection is often suggested as a means of reducing infrastructure conflicts: selecting an appropriately sized tree for the planting space; or avoiding species with characteristics that may conflict with infrastructure (Costello & Jones 2003). Species with greater damage potential include those with: a large trunk flare or root buttress; and those with roots that grow near the soil surface. In fact many arborists believe tree selection to be a key consideration in reducing tree/pavement conflicts (Bearnhardt & Swiecki 1993; Gilman 2001; Harris *et al.* 2004).

Species lists

Preferred species lists prepared by local authorities may focus on such attributes as: tree size (often in relation to street size); rooting habits (often in terms of deep or shallow rooting habits); or trunk diameter/basal flare. Trees, however, tend to be 'plastic' in the way they adapt and fit into their growing environment. Never-the-less some species have been identified as being more prone to surface rooting, suckering and pavement damage (Harris *et al.* 2004; Ferrini & Fini 2009). A more effective approach than universal tree lists however, is for arborists to rely more on the knowledge of local colleagues in selecting non-damaging trees, and avoiding trees which appear to be responsible for a disproportionate amount of damage (Harris *et al.* 2004).

Tree size

Several references address tree size and infrastructure damage (Barker 1983; Wagar & Barker 1983; Hamilton 1984a; 1984b; Day 1991; Kopinga 1993; McPherson & Peper 1995; Francis *et al.* 1996; Gilman 1997; Nicoll & Armstrong 1998; Syndor *et al.* 2000; Randrup *et al.* 2001a). Some use tree height and growth rate as a measure of potential for infrastructure damage, however diameter at ground level (DGL) is often a more direct measure (Costello & Jones 2003). DGL is a measure of trunk flare or root buttress as well as trunk diameter, and in some species may be 2-3 times trunk diameter at breast height, at maturity. Costello and Jones (2003) present a table from a survey undertaken in the San Francisco Bay area relating DGL and DAFB (diameter above flare and buttress) in a TDR (trunk diameter ratio), for a range of common species (Warriner 2000). Trunk flare and root buttress are commonly associated with hardscape damage (Wagar & Barker 1983). Planting site size should be related to DGL, and species with large root flare should only be used in large planting sites.

Some cities are now planting smaller stature tree species such as the crepe myrtle (*Lagerstroemia indica*) in large numbers to reduce infrastructure damage. While this may reduce damage, it also reduces the benefits delivered by larger stature trees (McPherson & Peper 2000). However some cities, such as Redwood City, California recognize the benefits of large scale shade trees and have a 'no toy trees' policy, planting larger stature trees and addressing infrastructure conflicts by other means (Costello & Jones 2003; Redwood City 2008).

Rooting habits

It is also commonly recognized that tree species with shallow roots or a large root mass have higher hardscape damage potential. In Mexico, potential for hardscape damage was related to tree species as well as distance from trunk to pavement (Francis *et al.* 1996). Municipal arborists often maintain lists of preferred species, and species thought to cause conflicts. However such lists may also be based on selection criteria other than root characteristics. Costello and Jones (2003) present a list identifying species associated with surface rooting characteristics or infrastructure damage, derived from a range of sources. However the list does not take account of the particular environmental variables that influenced root growth.

Another approach is to select and propagate species on the basis of rooting habit, with preference to trees which appear to have naturally deeper root systems (Coutts 1989; Nicoll & Armstrong 1997; Nicoll & Coutts 1997; Burger 2000; Burger & Prager 2008). Another option to explore is genetic improvements to create trees better suited to the urban environment (Day 1991). A further option with grafted cultivars would be to select rootstocks with less hardscape damage potential, and correct identification of rootstock at the nursery is therefore an important consideration (Costello *et al.* 2000). However, despite these considerations, the most commonly planted trees may in fact be the most damaging, due to the ready availability of those species (Barker 1988).

7.2.5 Infrastructure based practices

Hardscape materials

Pavements can be strengthened to increase resistance to displacement using either thicker or more heavily reinforces pavements (Costello & Jones 2003).

The flexibility of concrete pavements can be increased through the use of construction joints. Sacramento, California has also experimented with foam additives to increases concrete flexibility (McPherson & Peper 1995). There are also a number of more flexible alternatives to concrete pavements. Asphalt is flexible, relatively inexpensive and can be coloured. It lacks the strength of concrete but can be more easily replaced, however radial surface roots can cause it to bubble or ripple (Costello & Jones 2003). Decomposed granite is relatively inexpensive, easily installed, is porous and easily replaced, however it can erode. With a stabilizer added it becomes more stable, but less permeable and subject to cracking (Costello & Jones 2003). Unit pavers have aesthetic benefits, and can be easily lifted and replaced, and are more porous than concrete (subject to maintenance to avoid clogging with debris). However they are also more easily lifted by roots and can create tripping hazards, and are more expensive to install. Unit pavers require a smooth well compacted subgrade, usually sand, and extensive root development in the sand base has been reported in Germany and Denmark (Randrup *et al.* 2001a; Costello & Jones 2003).

Recycled rubber has been used as a substitute for concrete in southern Californian cities (Costello & Jones 2003). Santa Monica, California has experimented with rubber footpaths. While these displace more easily, they are also more easily repaired or replaced. When distorted by roots they also present less of a tripping hazard compared with conventional pavers. They also provide a more porous surface. They are typically installed following root pruning as a replacement pavement, which can be lifted and replaced for periodic root management at a fraction of the cost of replacing concrete (Harris *et al.* 2004). Installation costs are higher than concrete but will decrease as their use increases (Warriner 2002). The use of recycled materials also has environmental benefits. Rubber pavers can be installed as individual pavers or a single surface, on a compacted sand base (http://rubbersidewalks.com/).

There is also increasing interest in the use of permeable pavements in urban streets, with associated environmental benefits of reduced stormwater runoff and downstream pollution (United States Environmental Protection Agency 2000). One option is porous concrete which has an open void structure (15-20% by volume) due to the absence of sand in the mix. It allows air and water to pass through, and is nearly as strong as standard concrete (Costello & Jones 2003). As an example the City of Sumida in Japan is resurfacing its footpaths with permeable pavements to increase groundwater recharge. One sixth of the city's footpaths are permeable and the city intends to convert all footpaths to permeable pavement (UN Earth Summit+5 1997).

Hardscape design

Planting geometry

It would seem obvious to avoid planting potentially large trees in small confined spaces or pavement openings, however such practices still continue (Harris *et al.* 2004). A number of studies have examined the relationships between tree planting geometry and hardscape damage (Barker 1976; Barker & Durrant 1978; Wagar & Barker 1983; Wong *et al.* 1988). As expected, hardscape damage increases with trunk diameter and decreases as planting strip width increases. However it should be noted that hardscape damage may not occur for a number of years as the size of the tree increases relative to the opening, and infrastructure damage is often caused by trees outgrowing their planting space (Hamilton 1984b). The larger the planting space, the less likelihood of damage from trunk expansion, buttress development and surface root development. In England, Wong *et al.* .(1988) found the most severe pavement damage within 2 m of the tree trunk, and recommended that trees be planted in strips wider than 3.0 m, or in minimum 2 m square pavement openings. Francis *et al.* (1996) found damage potential increased significantly as distance to the tree reduced, and suggested a distance of 5 m may be needed between footpaths and very large trees. Mann (2003) suggests that larger shade trees should have a minimum planting strip width of 2.5 m. Craul (1992) advises that trees should not be planted in a space less than the extent of their mature framework roots, and the width between kerb and footpath should not be less than 1200 mm, preferably 1.5-1.8 m. Craul also advises that trees with known shallow root systems should not be planted close to infrastructure, or where severe soil compaction exists at shallow depths. Urban (2007) recommends that each tree planting detail be designed to suit its unique site context and surrounding soil conditions. He also identified four main options for planting trees in pavements, including a minimum 3 m wide planting strip.

In 1997 Gilman provided useful guidelines for matching mature tree size and planting space, based on three basic design options, each with associated community costs and benefits, as follows (Gilman 1997 p.25).

> ***For communities with a short-term view***. *Design the site so roots essentially remain in the small soil area of the cutout (this is the most common).*
> *Result: Tree grows slowly, dies and is replaced 5 to 10 years after planting; the sidewalk stays mostly intact.*
> *Costs: Inexpensive to install; recurring but known cost of replacing trees every 5 to 10 years.*
> *Community benefit: Little. Trees are rarely healthy and never become large; they provide little shade. This is a poor investment because money is spent with little benefit to anyone.*
> ***For communities with a medium-term view***. *Design the site so roots grow out of the soil in the cutout and into the soil under the walk.*
> *Result: Tree grows well and is fairly healthy, but sidewalk often heaves and the tree is blamed.*
> *Costs: Larger initial cost; recurring costs and root damage from fixing pavement.*
> *Community benefit: Significant. Tree grows well and becomes large, providing significant shade, but it is often damaged during pavement repair.*
> ***For communities with a long term view***. *Design the site so roots grow out of the soil in the cutout and under the walk in an engineered fashion.*
> *Result: Tree grows well and is healthy; sidewalk remains intact.*
> *Costs: Largest initial cost but no recurring costs.*
> *Community benefit: Significant. Tree grows well and becomes large, providing significant shade.*

Gilman (1997) also presented a set of planting area guidelines, noting that the minimum acceptable cutout size of 1200 mm by 1200 mm for small trees should be increased to 1800 mm by 1800 mm for larger-maturing trees, which is summarized in Table 35.

Table 35: Planting area guidelines

NOTE:
This table is included on page 135 of the print copy of the thesis held in the University of Adelaide Library.

Source; Gilman (1997) p.23.

Costello and Jones (2003) identify a range of streetscape design options to increase surface area for trees and to increase separation between tree trunks and surrounding infrastructure. Footpath options include: curved footpaths; and narrowing footpaths to minimum disability standards (usually around 1 m in the US). Verges can be widened by moving the kerb out into the parking lane (subject to maintaining stormwater drainage). Footpaths can be installed adjacent to the kerb rather than the property boundary, increasing planting space for the tree, and increasing separation between the tree and the kerb. Disadvantages include the loss of a buffer zone between pedestrians and vehicle traffic. In the United States, in constrained situations, easements may be obtained to construct footpaths on private property, increasing verge space for trees. In some situations footpaths can be eliminated entirely, increasing tree space and removing the hardscape element, or be located on one side of the road only, most appropriate in rural or cul-de-sac situations with little traffic. Another option is to create narrower vehicle carriageways in streets, allocating greater space to verges, and this can be carried out in conjunction with 'traffic calming' strategies, and strategies to enhance permeability.

Trees can be planted in groups in large 'tree islands' rather than in individual tree pits, reducing potential contact with hardscape. Trees also benefit from sharing a common soil volume with the benefits of: more effective soil and water management; and creating improved environmental conditions such as wind protection.

Vertical separation

One practice sometimes adopted in an attempt to reduce hardscape damage is to plant trees with the tree pit surface lowered below the level of the surrounding pavement (usually 45-50 cm) (Costello & Jones 2003). Since the 1970's Santa Monica, California has planted many of its trees 0.5 m below the footpath (Wagar 1985; Harris *et al.* 2004). Beaudoin (2000) has noted that planting Sycamore (*Acer* spp.) trees below grade was effective in preventing lifting of adjacent pavers, over a twenty year period. Mulberry (*Morus nigra*) and Zelkova (*Zelkova* spp.) trees planted 450mm below the surrounding surface level showed lesser root growth in the top layer of soil compared with surface planted trees (Wagar 1985). Usually a trafficable surface is required over the lowered sites to reduce pedestrian hazards. This is often achieved with a metal tree grate, and issues of litter accumulation can be addressed by filling the void below the grate with a coarse aggregate. A related remedial practice is installing bridges or ramps over tree roots, and Costello and Jones (2003) provide useful technical details from the City of Los Angeles.

This strategy has reportedly been met with mixed results (Costello & Jones 2003). Costello and Jones (2003) cite examples in San Jose, California, with trees planted 46 cm below grade and backfilled with pea gravel (successful in terms of reduced pavement damage after twenty years), and Santa Monica, California planted 46 cm below grade in concrete vaults (with issues occurring after twenty years, but less than those with similar trees planted at grade in footpaths after ten years).

Footpath construction profiles

Footpath construction profiles can also be modified to allow footpaths and tree roots to better co-exist by: limiting root growth under footpaths; or allowing roots to grow without damaging the footpath (Urban *et al.* 1989).

Tree roots have been found to flourish in the gravel layer directly below the footpath, due to the favourable environmental conditions there, and the inability of roots to penetrate the compacted sub base below the gravel layer. In particular water condensation below pavements creates favourable conditions for root growth (Wagar & Franklin 1994). High soil moisture levels below pavements have been found to be a major factor in shallow rooting in the Netherlands (Kopinga 1993). As roots increase in diameter they can lift and crack pavements. A number of attempts have been made to modify the gravel layer to discourage growth (Costello & Jones 2003). One option is the use of larger gravel (greater than 19mm) which creates larger air spaces which reduce water retention to the point of limiting root growth (Coder 1998). A second option is a thicker layer (20-25 cm deep) at the edge of the pavement closest to the tree, with the thicker gravel intended to reduce the lifting force of the root (Costello & Jones 2003). A third option is to eliminate the gravel layer, encouraging roots to grow below a compacted upper layer and into the soil below. This would only be effective if soil conditions were conducive to root growth. In addition the gravel layer may also be required to provide a stable base for concrete slabs (Costello & Jones 2003). Alternatives to gravel have also been explored including the use of recycled concrete (PCC) in the City of Los Angeles (Costello & Jones 2003). Trials have also been conducted with a Styrofoam underlay below footpaths to allow root growth without hardscape damage (Urban *et al.* 1989).

Synchronized tree/hardscape life

Hardscape such as pavements cannot be expected to last forever, but only for a certain useful service life (McPherson & Peper 1995; Syndor *et al.* 2000). A logical approach may be to replace both trees and pavements at similar intervals, and matching tree and pavement life expectancy would assist in reducing physical damage and servicing costs for both trees and infrastructure (Costello & Dodge 2001).

7.2.6 Rootzone based practices

Soil management

The environment below pavements, even laid on compacted soils, is favourable to root growth, and is often the only zone that roots can enter. Roots may enter the gravel bedding layer between the pavement compacted soil. Differential temperature and moisture induced expansion and contraction can also create a gap between the pavement and soil where roots can enter (Gilstrap 2001). One option is the use of structural soils which allow roots to explore at deeper levels due to improved conditions for root growth at depth (Grabosky *et al.* 1998a).Another approach is 'root baiting', based on the concept that roots will avoid areas with poor resources for growth, and will seek resources elsewhere (Coder 1998; Costello & Jones 2003; Lawry 2005a). As summarized in Table 36, Moore (2008) advocates managing soil conditions to manage root growth, to discourage root growth where it is not wanted (in proximity to infrastructure) and encourage it in more appropriate areas.

Table 36: Management strategies for the manipulation of root growth

NOTE:
This table is included on page 138 of the print copy of the thesis held in the University of Adelaide Library.

Source: Moore (2008).

Costello and Jones (2003 p.55) however, caution that

> *Attempting to control root distribution by controlling soil moisture distribution must be viewed as a much greater challenge that is likely beyond the capability of most municipal tree care programs.*

Root barriers

Introduction

Root barriers are probably the technique most commonly adopted by authorities attempting to reduce street tree/infrastructure conflicts (Bearnhardt & Swiecki 1993). They comprise a family of devices with the stated aim of reducing infrastructure conflicts by restricting root growth, or directing it to deeper soil levels. Root barriers are installed to protect pavements, kerbs, structures and underground services (Craul 1992).

Root barriers, however, have also been criticized for addressing the symptoms rather than the cause of tree/infrastructure conflicts. The ideal solution is to address the problem at the planning stage in terms of the correct placement of trees and infrastructure, as well as tree species selection and infrastructure construction techniques. In addition, unfavorable soil conditions may lead to roots behaving differently than depicted in industry advertisements (Craul 1992).

Types of root barriers

A number of researchers have documented the available range of different root barrier technologies (Barker 1993; Peper & Barker 1993; Barker 1995; Barker & Peper 1995; Urban 1995; Gilman 1997; Morgenroth 2008). Peper and Barker (1993) have outlined the characteristics of the more effective products.

Three main types of barriers are commonly identified: deflectors; inhibitors; and traps (Costello & Jones 2003). Deflectors are the most commonly used, and physically direct roots laterally or downwards (http://www.rootbarrier.com.au/ http://www.arborgreen.com.au/). Some have vertical ribs to channel roots downwards and discourage encircling roots. Root deflectors are generally of plastic construction, however concrete aprons (extending 15-20 cm down from the kerb) have been used as root deflectors in Los Angeles (Costello & Jones 2003). Inhibitors comprise fabrics or screens impregnated with chemicals (such as slow release trifluralin) to inhibit root development (http://www.biobarrier.com/), however some species can penetrate such barriers (Wagar & Barker 1993). Traps are screens or sheets with holes small enough for root tips to penetrate, but which inhibit radial growth (Wagar & Barker 1993). Morgenroth (2008) identifies a fourth type of barrier known as a three dimensional barrier. This type of barrier creates soil conditions that inhibit root growth, such as air gaps in a coarse gravel sub-base (Coder 1998; Gilman 2006). Each type of barrier can also be either linear or circular in configuration. In linear configurations the barrier is installed alongside all or part of the infrastructure, or the tree. In circular configurations the barrier is placed around the rootball of the tree (usually at the time of planting). The circular configuration, known as root director, is usually applied in footpath tree pits or other highly constrained settings with the barrier surrounding the rootball but open to the soil below (http://www.arborgreen.com.au/). However it has been suggested that unfavorable soil conditions may limit root development to the confines of the barrier, compromising root growth and anchorage (Costello & Jones 2003).

In terms of installation, both linear and circular configurations should be installed as far from the tree trunk as possible to allow for trunk flare and buttress development. A number of researchers have reviewed technical concerns in root barrier construction and installation, including: depth; need for retention of a lip above ground; preference for barriers with vertical ribs; and the need for intact connection joints (Wagar 1985; Harris *et al.* 2004)

Root barrier research

There are mixed findings in the literature regarding the effectiveness of root barriers. A key consideration is the ability of root barriers to protect infrastructure by directing roots to deeper soil levels and eliminating surface rooting. Wagar (1985) found that individual trees varied in the extent to which their roots returned to the surface after being forced deeper by tree planters and wells. He noted substantial surface rooting for some trees with barriers, and attributed it to soil compaction and aeration levels in parts of the study plot. Another study found that in two tree species, Raywood ash (*Fraxinus angustifolia* ssp. *oxycarpa* 'Raywood') and Italian poplar (*Populus nigra* 'Italica') roots returned to the surface after growing below circular barriers (Costello *et al.* 1997). Similar results were obtained by Gilman (1996) using a linear barrier with Live oak (*Quecus virginiana*) and Sycamore (*Platanus occidentalis*). Barker (1995) found that European hackberry (*Celtis occidentalis*) and South eastern black cherry (*Prunus serotina*) generated deeper root systems with root barriers in well-drained alluvial soils. However at the same site, Peper and Mori found that Chinese hackberry (*Celtis sinenesis*) and White mulberry (*Morus alba*) roots returned to the surface (Peper 1998; Peper & Mori 1999). Although species varied in response to root barriers, roots of Silver birch (*Betula pendula*), Norway maple (Ac*er platanoides*), Hawthorn (*Cratageus monogyana*) and Wild cherry (*Prunus avium*) were observed to grow upward from the base of a root barrier (Nicoll & Armstrong 1998). Urban (1995) noted tree roots growing down then up the other side of a 450 mm brick barrier. In another example the roots of trees grown in 600 mm diameter, 380 mm deep circling barriers also tended to grow towards the surface after growing under the barrier (Costello *et al.* 1997).

Gilman (2001) has summarized the research findings on root barriers and concludes there is a relationship with soil conditions, with roots in compacted soils tending to return to the soil surface. He suggests this may be due to aerated soil conditions being created during the installation of the barrier, including backfilling the trench in which the barrier is installed. Gilman (1996 P.154) observes that

> *Root barriers might be most effective in soils where they are least needed, i.e. in well-drained, non-compacted soils.*

And similarly Harris *et al.* (2004 p231) note that

> *…root-control devices appear to be least effective where they are most needed, that is, where compaction and poor soil aeration encourage shallow rooting.*

This reflects the observations of Craul (1992) that the greatest risk to infrastructure from trees occurs where severe soil compaction exists at shallow depths, and that root barriers will only be effective at diverting roots if the deeper soil conditions are favourable to root growth.

More recently Gilman (2006) has tested the effectiveness of a range of barriers on the impacts of Plane trees (*Platanus orientalis*) planted 75 cm from concrete footpaths (installed in 1996), using both well-drained and poorly-drained test sites. Installations included a control with no barrier, a 30 cm deep polyethylene barrier, proprietary Biobarrier™ and Deep Root™ barriers, and a 15 cm deep clean gravel layer. No roots grew in the gravel in the well-drained site, resulting in significantly deeper root systems (19 cm deep) compared with the other treatments (11 cm deep). Vertical barriers did not increase root depth compared with the control, on the well-drained site. Gravel and Biobarrier™ were the most effective on the poorly-drained site. Roots deflected by the vertical barriers were forced deeper into the soil, but many returned to the surface by the time they reached the opposite side of the footpath. Gilman (2006 p.18) concluded that

> *Gravel under sidewalks appears to hold promise for reducing sidewalk damage, especially on well-drained sites.*

Researchers have also investigated the effects of root barriers on tree stability. Trees in root control devices appear to grow as fast as those without (Wagar 1985; Costello *et al.* 1997; Peper & Mori 1999a; Smiley *et al.* 2000). Trees grown in root control barriers have also been reported as being more stable, attributed to deeper rooting behaviour (Smiley *et al.* 2000). However Costello and Jones (2003) suggest that buttress development and anchorage may be compromised by root barriers.

7.2.7 Remedial treatments

Remedial practices, undertaken after hardscape damage has occurred, are not discussed here in detail. Remedial actions have two roles: to reduce the disruptive tendency of the tree; and to repair, and possibly improve the hardscape design (Harris *et al.* 2004). Remedial treatment may often be a compromise between: sound tree management needs; engineering requirements; and public acceptance. Costello and Jones reviewed a number of remedial practices to manage pavement displacement (Costello & Jones 2003). Beaudoin (2000) also reviewed the cost effectiveness of different remedial strategies.

Ramping, patching and grinding can be undertaken to even out discontinuities and reduce tripping hazards, but fails to address the underlying cause. Root pruning removes the offending roots, but may require pavement removal for access. Few arborists, however, appear to be satisfied with root pruning practices (Hamilton *et al.* 1975; Hamilton 1988).The long term effects on tree health and structural stability appear to be species dependant (Bearnhardt & Swiecki 1993; Warriner 2000).

Footpaths may be removed and replaced, often in conjunction with root pruning. However a wide range of variations can be implemented, rather than simply duplicating the original layout that contributed to the problem in the first place (Harris *et al.* 2004). Options include: installing unit pavers rather than monolithic concrete; moving pavements away from tree roots and tree trunks to increase separation; ramping over roots; relaying paving with a void, or backfilling with gravel or foam to create a space for root expansion; reinforcing paving to increase strength; installation of root barriers as a remedial measure following root pruning (Wagar & Barker 1983); and installation of flexible rubber pavers. Rubber pavers may be displaced by roots, but can be easily lifted and replaced after root pruning, reducing repair costs. The ability to access roots without destroying the pavements is a significant advantage.

Tree removal is the most radical 'remedial treatment', and most commonly 'repeat offenders' are removed. In parts of the United States repair costs may be borne by the adjacent property owner, resulting in community support for tree removal where repair costs are significant (Harris *et al.* 2004). Highway engineers may also be reluctant to allow replanting due to concern with recurring future problems (Patch 1994).

Redwood City, California (http://www.redwoodcity.org/publicworks/trees/tree_sidewalk.htm) has one of the most innovative footpath repair programs, aimed at modifying the public right-of-way to create the greatest possible area for future tree growth (Harris *et al.* 2004; Redwood City 2008). A key aim is to increase the space between the footpath and the tree to allow a minimum separation of 1 m, with the optimum separation being 2 m. To meet this target the following options can be implemented (Costello & Jones 2003 p.63).

a) *Sidewalk narrowed to 1.2 m.*
b) *Sidewalk curved to the back edge of the right-of-way.*
c) *Redwood City obtaining an easement to locate the public sidewalk on private land.*
d) *The sidewalk located next to the kerb and the tree planted adjacent to the property boundary.*
e) *Where there is a narrow planting strip, a tree grate may be built into the part of the sidewalk close to the tree.*

Redwood City also has a number of other valuable policies including the following (Harris *et al.* 2004 p.235).

a) *Retaining as many large trees as possible.*
b) *No 'toy trees', the goal being to plant larger scale shade trees to provide a significant canopy over the street.*
c) *Tree removal as the last option, as trees takes a long time to develop and are not easily replaced in terms of size or canopy spread.*

Future directions

To some arboricultural authorities the long term solution to tree/hardscape conflicts appears to be the selection of 'deep rooting' tree species (Burger 2000; Burger & Prager 2008). In the near and medium term, however, the focus should be on a multi-disciplinary approach combining a number of factors including: species selection; remediation of compacted soils; use of root barriers; and alternative pavement designs (Harris *et al.* 2004). Arborists also need to educate their counterparts in other fields, elected officials, and the public, that the problem is complex and requires solutions beyond that of simple tree removal (Harris *et al.* 2004).

7.2.8 Conclusion

Conflicts between tree roots and the hardscape of streets is probably the main issue to be dealt with by urban tree managers, especially in constrained urban sites. Hardscape damage is a concern in many cities, not just in terms of repair costs, but also with public liability. In addition the tree also suffers in such conflicts, which can lead to tree removal and constraints on future planting. The cause of tree root damage can be either direct or indirect, and is often due to the favourable conditions beneath pavements installed over a compacted sub base. Strategies to minimize conflicts can be tree based, infrastructure based or rootzone based. The key to success, however, is in the early design stages, ensuring that trees are giving realistic space, both above and below ground, for root development without impacting on the adjacent hardscape. Table 37 provides a summary of key hardscape strategies and practices identified in this section of the thesis.

Table 37: Summary of hardscape related practices

Strategy	Practice	Comment
Tree based	Species selection	Size, rooting habit, basal flare
Infrastructure based-materials	Strength	Reinforcing
	Flexibility	Alternative materials
Infrastructure based-design	Planting geometry	Space, separation
	Footpath options	Curved footpaths, narrow footpath, protuberance, footpath by kerb, no footpath, footpath one side only, footpath easements
	Street design options	Reduced carriageway width
	Tree islands	
	Vertical separation	
	Synchronized tree/asset life	
Rootzone based	Soil management	Root baiting
	Root barriers	Deflectors, inhibitors, traps, gravel
Remedial treatments	Repair	
	Root pruning	
	Tree removal	
	Replacement alternatives	

7.3 Building conflicts

7.3.1 Introduction

Trees can cause damage to buildings and other structures, either directly, or more commonly indirectly through their influence on soil moisture in expansive soils (Roberts *et al.* 2006).

7.3.2 Damage mechanism

Direct damage is caused by the physical forces exerted by roots, most commonly by radial growth as the tree matures. It is most severe near the base of the tree and decreases with distance. However both the longitudinal and radial pressures exerted by roots are relatively weak, and they will tend to distort around objects rather than displace them, in relatively loose soils (MacLeod & Cram 1996; Biddle 1998).Indirect damage is associated with the effects of the shrinking and swelling of sub-base soils on building footings (BRE 1993). In particular, some types of clay soils shrink and expand as they dry and wet, leading to cracking and subsidence in pavements, footings and walls (Cutler & Richardson 1989). Trees may be implicated in the process, as water demand through transpiration can exacerbate changes in soil moisture and volume. It is possible to make reasonable estimates of water usage of large trees, and water losses through transpiration in summer can be enormous. A single large tree can transpire the equivalent of 380 litres of water on a sunny day (Perpich,Lukas & Barker 1965). Water losses due to canopy interception of rainfall by large trees can also be significant (Prebble & Stirk 1980).

Under *Australian Standard AS2870* desiccation of the soil profile, and predictions of soil volume change, is defined by total soil suction. As water is lost from the leaves during transpiration, a negative potential or suction is set up in the leaf (Kozlowski 1982). This provides the 'pulling' power to extract water from the soil via the roots, and draw it through the plants continuous xylem system to the leaf (Biddle 2001). High soil suction infers low soil moisture content, and the usual range in semi-arid climates is 100 kPa to 10 MPa. At very high levels of soil desiccation vegetation is unable to extract further water from the soil, known as wilting point, which varies between species. Lawry provides a useful tabulation in Table 38 which summarizes approximate relationships between soil suction, soil water status and the implications for tree condition and footing risk (Lawry 2008).

Table 38: Relationship between suction and soil/plant conditions (approximate)

NOTE:
This table is included on page 145 of the print copy of the thesis held in the University of Adelaide Library.

Source: Lawry (2008) Appendix 7.

Tree root systems can generate shrinkage settlement at considerable depths of over 4 m (Richards *et al.* 1983; McInnes 1986). Cameron (2001) has found trees causing deep drying in Adelaide soils to a depth of approximately 4 m for an isolated tree, and 6 m for a group of trees.

Research data on the role of trees in soil desiccation are very limited, especially in urban environments. There is, therefore, a lack of rationally based guidelines for tree planting, or footing design in the presence of trees, on reactive soil sites (Cameron *et al.* 2006). Researchers at the University of South Australia are conducting two major investigations. One project examines the feasibility of stabilizing poorly drained clay soils under rail formations by revegetating a rail corridor. The results indicate that trees in the right situations may actually assist in stabilizing foundations. The second is a long term study of the influence of a range of street trees on soil moisture patterns within a modern housing estate. Most of the sites monitored are reactive clay soils, and preliminary results indicate that water demand is species dependant, however the differences between evergreen and deciduous trees may not always be so distinct, as evidenced by a comparison between the Coral gum (*Eucalyptus torquata*) and Chinese elm (*Ulmus parvifolia*) monitored in the study (O'Malley & Cameron 2005; Cameron *et al.* 2006)

7.3.3 Building damage studies

A number of researchers have investigated the role of trees in building damage, however much is based on indirect evidence. Some sources relate building damage to tree height or tree species. In the United Kingdom, Ward (1953) recommended safe planting distances from buildings to avoid damage from soil shrinkage, prescribing the first proximity rule of D:H=1. Hammer and Thompson

(1966) found severe damage has been recorded with large trees within 12 m of buildings. Further research was initiated in the United Kingdom in response to widespread damage observed during a severe drought in the 1970's (Biddle 1983; Driscoll 1983; Cutler & Richardson 1989). Biddle (1983; 2001) conducted studies of soil moisture deficits around several tree species in different clay soil profiles in open grassland. Lateral drying was generally contained within a radius equal to tree height; however the depth and radius of drying was related to tree species. Cutler and Richardson (1981; 1989) reported on 2,600 cases of building damage in the UK, setting up a database relating tree species, proximity to buildings, and building damage. Of common English trees, Oak (*Quercus* spp.) and Poplar (*Populus* spp.) were the two genera most associated with damage. However Cutler and Richardson also found a poor correlation between tree height and damage. Young trees with rapidly emerging roots caused more problems than mature trees. Shrinking and swelling have been found to be greatest near the surface where most roots are located (Pryke 1979).

In the United States a study by Tucker and Poor (1978) indicated that tree effects were significant at a D:H value greater than one. Harris, Clark and Matheney (2004) provide a summary of tree species associated with building damage on expansive soils, compiled from a range of sources. In New Zealand Wesseldine (1982) examined the effects of *Eucalyptus* species on houses, indicating damage threshold values of D:H=0.75 for single trees and D:H=1.0-1.5 for groups of trees.

Early research in Australia in the 1980's was largely related to building damage appraisals. Cameron and Earl (1982) published information on potential tree damage to houses, based on the occurrence of root blockages of the Engineering and Water Supply Department (EWS) pipe network in Adelaide, South Australia. Studies in Melbourne concluded that significant damage to brick veneer house on strip footings was likely if tree proximity was less than or equal to 0.5 tree height (Cameron & Walsh 1984). A study of soil suction of three different tree species in the Adelaide Parklands, South Australia (*Eucalyptus*, *Casuarinas* and *Pinus* spp.), found that *Eucalypus* species had the greatest drying effect, and the radial extent appeared to be 1.3 times average tree height (Richards *et al.* 1983)

7.3.4 Other contributing factors

It is important to recognize that factors other than trees may be involved in building damage on expansive clay soils. However trees are often demonized by engineers (Lawry 2008). Trees are often implicated in building damage by their mere proximity with no other evidence (Chen 1975;` 1992). Holz (1983) estimates that only 20% of damage on expansive soils may be attributed to vegetation. Vegetation other than trees can also contribute soil desiccation (Holtz 1983). Climate also has a significant effect, and soil movement will be greater where heavy rainfall periods are followed by severe droughts, compared with areas where rainfall is more evenly distributed over the year (Harris *et al.* 2004). A careful examination of site factors is therefore required before reaching a diagnosis.

Several conditions are required for significant structural damage to occur due to interactions of soil, moisture and roots (Harris *et al.* 2004). These include the following

- The soil must be of a type that shrinks when dry, however problematic soils may be overlain by non-expansive soils (Chen 1975).
- The tree must be of sufficient size to use large amounts of water, and must be able to penetrate the expensive soil, which may be poorly aerated at depth (Perpich *et al.* 1965).
- The structure must rely on the underlying soil for stability, and buildings with shallow footings are the most susceptible to damage (Kelsey 1987).

7.3.5 Extent of the problem

Building damage implicating trees has been reported in many parts of the world including the United Kingdom (Driscoll 1983; McCrombie 1993) and Australia (Richards *et al.* 1983). Concern by householders and insurance companies has led to anxiety about trees in proximity to buildings (Biddle 1998). Soil shrinkage can be especially severe during droughts resulting in large insurance claims (Reece 1979). Even if structural integrity is not effected by subsidence, it can still impact on the appearance, value and marketability of buildings (Pryke 1979). In South Australia buildings must withstand significant soil movements due to the combination of reactive clay soils and a semi-arid climate, and trees can add to these movements resulting in unacceptable cracking (O'Malley & Cameron 2005; Cameron *et al.* 2006).

7.3.6 Current design standards

According to Cameron (2006) generally masonry and brick-veneer houses over ten years old in Australia have not been designed to cater for the drying effects of trees. And even more recent construction designed to meet the requirements of *Australian Standard AS2870-1996* remains susceptible to damage, as the Standard does not provide directly for the influence of trees on footings (Standards Australia 1996). Rather the *Standard* encourages avoidance of extreme moisture changes by distancing trees from buildings, and does not provide guidelines for designing footings with trees close to dwellings. It recommends proximity rules in terms of the ratio D:H (horizontal separation distance and mature tree height) which are often more extreme than Ward's original rule of D:H=1 (Ward 1953). In addition the *Standard* does not differentiate between different tree species. Thus D:H increases with the level of site classification for expansive clay soil movement. Appendix B of the Standard (*Performance Criteria and Foundation Maintenance*) (Standards Australia 1996) states

> *Planting of trees should be avoided near the foundations of a house or neighbouring house on reactive sites as they can cause damage due to drying of the clay at substantial distances. To reduce, but not eliminate, the possibility of damage, tree planting should be restricted to a distance from the house of:*
> *1.5 x mature height for Class E sites*
> *1 x mature height for Class H sites*
> *0.75 x mature height for Class M sites*
> *Where rows of trees are involved, the distance from the building should be increased. Removal of trees from the site can cause similar problems.*

In Australia new homeowners may also be provided with a pamphlet *Foundation maintenance and footing performance: a homeowner's guide*, which advises of the threat of shrinkage settlement caused by trees close to buildings on reactive clay sites (CSIRO 2003). Such controls on tree siting, however, have implications with the trend to smaller lot sizes and reduced boundary setbacks where the prescribed distances could imply a future with treeless streets in areas of reactive clay soils (Cameron *et al.* 2006). According to Percival (2004 p.122)

> *The only guarantee on shrinkable soils that trees will not cause damage to structures with shallow foundations, is to ensure that the tree-to-building distance is greater than the maximum tree root radius. Although this is a logical approach, if adopted would eliminate trees in the urban environment.*

Engineers attempt to minimize shrinkage by excluding trees, or designing for anticipated soil movement with trees present. However such 'tree designs' are based on empirical observations rather than systematic knowledge of the relative water usage of different species on an urban environment. Without such data footings may be either under-designed (and subject to damage), or overdesigned (at excessive cost). Adelaide, South Australia, and its suburbs experience the most powerful combination of expansive soils and adverse climate of any Australian capital city, and footing designs developed there can provide guidance for the rest of Australia (O'Malley & Cameron 2005; Cameron *et al.* 2006).

7.3.7 Practices

Harris *et al.* (2004) provide a summary of practices to correct or avoid damaging tree impacts on buildings.

Tree based practices

Tree-based practices include tree setbacks from structures, tree species selection, tree removal and site water management.

Separation of tree and structure

Recommended separation distances vary, from a distance equal to tree height (Perpich *et al.* 1965) to half tree height (Hammer & Thompson 1966). The British Standards Institute identifies separation distances for common English tree species. The Royal Botanic Gardens in Kew have played a useful role with intensive efforts to synthesize the results of field studies into practice guidelines (Gasson & Cutler 1998).

Tree species selection

Ideally tree species should be selected that contribute less to soil desiccation. Soil problems would be expected to be less for trees with relatively low transpiration rates and small, shallow root systems. Unfortunately few species appear to have been tested for these features (Harris *et al.* 2004). Drought tolerant species with low rates of water use may be recommended, however these should not be confused with trees that are 'water spenders', which appear to be drought tolerant, but which transpire freely and survive through an extensive root system. Such species include many Eucalypts (Harris & Coppock 1977). In the UK, McCombie (1995) provides guidance on the risks of damage due to water demand of different trees. Modifications are also proposed to the *UK National House Building Code* guidelines to take into account the D:H values of common UK tree species, water demand, height and soil shrinkability (Percival 2004).

Tree removal

Tree removal is sometimes considered an option, which can have unforeseen detrimental consequences such as soil expansion and increased structural damage. According to Percival (2004 p.123)

> *Recorded cases exist of recommended activity having the opposite effect to that desired, complete removal can lead to expansion of shrinkable clay soils and resultant heave.*

Water management

Strategies to help preserve uniform soil moisture levels and avoid extremes of wetting and drying include: irrigation; mulching; and adequate surface drainage to avoid ponding (Day 1992).

Infrastructure based practices

Infrastructure-based practices include improved structural designs, and the use of root barriers.

Structural design

Structures can be designed to tolerate anticipated soil movements, including the additional effects of vegetation. Footings should ideally extend below the zone of desiccation (Biddle 1979; Kelsey

1987; Day 1992). In the UK, Percival (2004) recommends providing buildings with deep, strong footings (for example 3m deep short-based piled footings, to provide stability at a reasonable cost.

Root barriers

Root barriers can be installed around footings to limit root growth. Refer to Section 7.2.6 for a detailed discussion of root barriers.

7.3.8 Conclusion

Trees are sometimes implicated in building damage, due to their effects on soil moisture levels and expansion and contraction in reactive clay soils. However trees may only be one of a number of factors involves in such damage, and are often blamed without any supporting evidence. Interactions of tree roots, soils and building footings (including species characteristics) are not well understood and current standards are often based on empirical observations only. A common strategy to minimize damage is a separation distance based upon mature tree height. However if such controls were rigorously applied there would be few trees in cities, especially with the trend to smaller allotment sizes and urban densification. The preferred approach would be one which allows trees and buildings to co-exist, with more appropriate footing designs based on a sound knowledge of tree, soil and footing interactions. Table 39 provides a summary of key building related strategies and practices identified in this section of the thesis.

Table 39: Summary of building related practices

Strategy	Practice
Tree based	Separation
	Tree species selection
	Tree removal
	Water management
Infrastructure based	Footing design
	Root barriers

7.4 Underground service conflicts

7.4.1 Introduction

Tree roots can enter underground services, especially sewer pipes, creating significant problems for service authorities (Rolf & Stahl 1994; Rolf, Stahl & Schroeder 1995; Randrup, *et al.* 2001b; Tomeo 2002).

7.4.2 Damage mechanism

Root entry into sewers is usually preceded by a failure of the sewer line itself. Common failures include a break in the pipe or failure at the pipe joints (Roberts *et al.* 2006). However it has also been noted that fine roots can penetrate a sealed connection (Mattheck & Bethge 2000). Once a root enters a pipe it will rapidly proliferate under favourable conditions of aeration, humidity and nutrient availability, leading to clogging of the pipe. As the roots grow they expand in size enlarging the initial entry point. Moisture escaping from pipe cracks can also encourage excessive root growth in the surrounding soil, leading to possible damage through pipe displacement (Roberts *et al.* 2006).

7.4.3 Extent of the problem

Problems with tree roots and underground services, especially sewer lines, is a worldwide issue (Roberts *et al.* 2006). Randrup *et al.* (2001b) provide an overview of the extent and costs of sewer root intrusions in the United States and Europe. Hitchmough (1994) has addressed the issue from an Australian viewpoint.

7.4.4 Practices

The most effective way to control roots in sewers is to prevent their initial entry. Strategies to prevent or delay intrusion can be tree based or infrastructure based (Percival 2004).

Tree based strategies

Tree based practices include tree species selection, and separation of trees and services. An important principle is to avoid planting fast-growing species that are known to have invasive root systems, in proximity to sewers. Trees with such a reputation include species of willow (*Salix* spp.), poplar (*Populus* spp.), birch (*Betula* spp.) and elm (*Ulmus* spp.) (Randrup 2000). Statutory measures may restrict tree planting in proximity to sewers and other underground services. In South Australia the *Regulations under the Waterworks Act* 1986 list 100 species not to be planted closer than 2 m to a sewer main, 95 species not to be planted closer than 3.5 m, and 30 species not to be planted in a street (South Australia 1996c). However conflicts can arise when services are located in easements in close proximity to tree planting verges.

Infrastructure-based strategies

Hitchmough (1994 p.281) emphasizes that it is not necessarily appropriate to ‘blame the tree’ in tree conflicts with sewer lines:

> *Tree roots do not seek out these services in search of water or other useful sources, but if they happen to be adjacent to a leaking sewer pipe, then they will proliferate in the moist, nutrient rich soil.*

…the problem is best addressed by engineering solutions such as pipes and ducts that are designed to resist root intrusion.

Infrastructure-based practices include improved design and construction practices, remediation of the initial damage, and the use of root barriers. More effective design and construction practices include the use of plastic, fibreglass and concrete pipes rather than traditional clay pipes (Rolf & Stahl 1994). Water-tight flexible, telescopic joints are also preferred (Percival 2004). Sewer leaks can be sealed to reduce root attraction, with pipe slip-lining and sealing with Penetryn™, a liquid dual compound acrylic gel pumped into joints (Percival 2004). Pipes can be wrapped in a variety of root barriers; either the whole pipe or the joints only. These can include copper wire screen (toxic to small roots), and products such as Biobarrier™, a root resistant geotextile with a time-release herbicide (trifluralin) (Roberts *et al.* 2006).

7.4.5 Conclusion

Tree entry into underground services, especially sewer lines, is a universal problem. However initial root entry is often due to failure of the infrastructure. Avoidance measures by authorities may focus on restricting tree planting in terms of species and separation distances. A more satisfactory approach, however, is the appropriate design of the infrastructure to allow both trees and services to co-exist in urban streets. Table 40 provides a summary of key underground service related strategies and practices identified in this section of the thesis.

Table 40: Summary of service related practices

Strategy	Practice
Tree based	Species selection
	Separation distance
Infrastructure based	Design and construction
	Remediation of damage
	Root barriers

8 Review of practices-Water Sensitive Urban Design

8.1 Introduction

Water Sensitive Urban Design (WSUD) can assist in achieving ‘green streets’ in times of drought and water restrictions. Stormwater runoff that flows off hard urban surfaces and drains out to sea can be harvested to recharge local soil moisture and irrigate street trees and other landscaping. At the same time, that runoff can be filtered and cleaned of pollutants by tree root systems, before returning it to aquatic ecosystems. Significant opportunities may exist to further integrate urban trees into WSUD initiatives, providing benefits to trees as well as to the urban water cycle.

8.2 Role of trees in the water cycle

Trees play an important role in the natural, and urban water cycle (Stovin *et al.* 2008). According to Day & Dickson (2008 p.6)

> *Natural forests with their complete canopy cover, large leaf areas, and permeable soils, handle rainwater effectively through interception and infiltration, returning water to groundwater and the atmosphere and protecting water quality in surface waterways*.

Tree canopies intercept and store rainfall, with the extent of interception influenced by a number of factors including tree architecture (Crockford & Richardson 2000). Canopy interception reduces runoff volumes and delays the onset of peak flows (Davey Resource Group 2008). It has been estimated that a typical medium sized canopy tree can intercept as much as 9000 litres of rainfall per year. Xiao *et al.* (2000) reviewed a number of papers reporting interception losses of 10-40% of annual precipitation. Interception losses vary between forests and open grown trees, and losses of 15% were recorded for open grown pear (*Pyrus* spp.) and 27% for open grown oak (*Quecus* spp.). Tree root growth and decomposition also increases the capacity and rate of rainfall infiltration and reduced overland flows (Bartens *et al.* 2008). And tree canopies help reduce soil erosion and surface transport by diminishing the impacts of raindrops on bare surfaces (Craul 1992). Trees also draw moisture from the soil through transpiration, increasing soil water storage potential (Stovin *et al.* 2008). For example it has been estimated that the daily water usage by each tree in an avenue of seventy English elms (*Ulmus procera*) at the Waite Arboretum in Adelaide is 500 litres in summer (Lawry 2008).

However, regardless of these benefits, little consideration is given to the issue of increasing land use pressures acting to reduce urban tree cover (Stovin *et al.* 2008). According to Day and Dickinson (2008 p.6)

> *Replicating elements of this hydrologic cycle in urban settings is difficult, because buildings, infrastructure and other urban denizens compete for land and resources.*

8.3 Water Sensitive Urban Design

The urban water cycle

Urbanization has created significant changes in the natural water cycle. This includes: increased volumes of stormwater runoff from impervious urban surfaces; and a decline in the quality of runoff from pollutants generated by human activities (Thompson & Sorvig 2008). Conventional engineering management of urban stormwater runoff has been driven by the attitude that stormwater has no value as a resource, is environmentally benign, and adds little to urban amenity (Wong 2006). Urban stormwater management practices have emphasized highly efficient drainage systems that collect and remove stormwater and discharge it downstream, to avoid stormwater ponding and flood risk, using an engineered system of above ground channels and underground pipes (Wong 2006). Such systems, driven by public health and flood mitigation concerns, however, have had significant negative environmental consequences. These include: to the contributing area, the loss of a local water resource; and to the receiving waters downstream, increased runoff and flooding, and the pollution of waterways, resulting in the decline of aquatic ecosystems. In addition it has resulted in the loss of a visual connection between human activities and the water cycle, with the natural processes being 'out of sight and out of mind' (Wong 2006).

WSUD

Water Sensitive Urban Design (WSUD) emerged in the 1990's as a new paradigm for the more sustainable management of the water cycle in the urban landscape (Argue 2004). WSUD includes more sustainable management of the three urban water streams: potable water; wastewater; and stormwater (Landcom 2004). A key focus is on stormwater management, based on a new attitude, that stormwater is a valuable resource; and an emerging set of 'best management practices', aimed at better replicating the natural water cycle and integrating it into the planning and design of urban areas at a range of scales (Lloyd *et al.* 2002; Breen *et al.* 2004). Key objectives as summarized in *Urban Stormwater: Best Practice Environmental Management Guidelines* (Victorian Stormwater Committee 1999) are to

- *Protect and enhance natural water systems in urban developments. Natural systems become assets which are protected rather than exploited, and which are then able to function effectively.*

- *Integrate stormwater treatment into the landscape. For example by incorporating multiple use drainage corridors that maximize visual and recreational amenity.*
- *Protect water quality by improving the quality of water draining from urban environments into receiving environments. Water can be treated by filtration and retention, to remove pollutants closer to their source, reducing pollutant impacts on the downstream environment.*
- *Reduce runoff and peak flows. Local detention, and minimization of impervious surfaces, can provide flood mitigation using numerous small storage points, rather than one large detention basin. This approach also reduces the demand for downstream drainage infrastructure.*
- *Add value while minimizing drainage infrastructure development costs. Reduced runoff volumes and peak flows reduces the development costs of drainage infrastructure, while enhancing natural features and value-adding to the development.*

A number of State and local authorities have adopted WSUD strategies or guideline documents (City of Melbourne 2005). These usually comprise a set of guiding principles and a set of Best Management Practices (BMP's). They may address the three 'streams' of urban water cycle management: potable mains water; stormwater and wastewater. Guiding principles adopted by the City of Melbourne include the following (City of Melbourne 2005 p.8).

- *Find ways to reduce potable mains water demand. Through reducing consumption, and using alternative water sources for appropriate purposes.*
- *Minimize wastewater disposal. Through installing water efficient appliances and re-use of wastewater.*
- *Stormwater treatment. Treat stormwater to meet water quality objectives for reuse and/or discharge to surface waters.*
- *Reduce the impact of urban development. Protection of catchment hydrology, particularly aquatic habitats.*

A key concept involves matching available water sources with appropriate uses. The four sources are: potable mains water; stormwater (roof runoff and surface runoff); wastewater (light grey water, greywater and blackwater); and groundwater. The philosophy of 'fit-for-purpose' water use would see potable (drinking-quality) mains water replaced with other water sources where appropriate (City of Melbourne 2005). For example reused stormwater is a better alternative for landscape irrigation than drinking quality water.

WSUD guidelines also typically include a set of Best Management Practices (BMP's). These have been defined as

> *Structural and non-structural measures to reduce the impact of development on the urban water cycle* (Lloyd *et al.* 2002 p.34).

Non-structural BMP's include: environmental and urban development policies; environmental considerations on construction sites; education and staff training; community education programs; and enforcement programs (Lloyd *et al.* 2002). Structural BMP's (for stormwater management) include a range of physical practices addressing stormwater collection, detention, retention, filtration, conveyance, and reuse. These can be applied at the allotment, streetscape or regional scale. The list of structural BMP's will grow as more innovative practices are developed, adopted and integrated into urban design. A 'treatment train' approach is recommended combining a number of BMP's to achieve the desired objectives (Lloyd *et al.* 2002). The four main issues for advancing WSUD in Australia have been identified as: an appropriate regulatory framework; assessment and life-cycle costing; marketing and acceptance; and technology and design (Lloyd 2001).

Three basic approaches to urban stormwater management can be identified: the conventional approach (underground pipes convey and discharge stormwater directly to receiving waters): the downstream treatment approach (underground pipes convey and discharge stormwater to wetland with the treated flows discharged to the receiving waters); and the distributed treatment approach (in which smaller, localized treatments are distributed throughout the catchment) (Lloyd *et al.* 2002). WSUD applications have evolved considerably in recent years. Early WSUD stormwater treatment systems focused on large scale 'end of pipe' engineering solutions, such as wetlands and detention ponds, requiring large areas of land. More recently smaller scale 'at source' treatment measures have been developed, which can be adapted to small catchments and integrated into the urban fabric (Wettenhall 2006).These can be retrofitted into the existing urban setting, in street verges, traffic calming devices, public spaces, and car parks. According to Wong (2006) the success of such concepts in the 'public realm' depends on delivering outcomes that are: engaging, informative, cost effective, technically robust, and which achieve the desired environmental outcomes. This requires a high level of innovation, and inter-disciplinary collaboration between engineers, designers, and environmental specialists.

Streetscape scale applications

Streetscape scale best management practices (BMP's) can include permeable surfaces, biofiltration systems, infiltration trenches, swales, filter strips and mini-wetlands (Lloyd *et al.* 2002). Such applications can be designed in accordance with key WSUD stormwater management principles of: flow control (reducing stormwater runoff volumes and peak flows); improving water quality; and reducing impacts on receiving waterways through pollutant removal and retardation of stormwater flows. They also comprise stormwater collection and treatment 'at source' rather than 'end of pipe'. In addition they are a means of integrating stormwater treatment into the urban landscape or streetscape, and achieving multiple use of valuable urban street space including stormwater treatment, urban greening if vegetated systems are used, and enhancing the visual quality and visual interest of streetscapes. As such they can value-add to urban streetscapes. Well designed streetscape applications can also play a valuable role by increasing awareness of the connections between human activities and their impacts on the water cycle, by making those processes more visible.

In addition, streetscape scale applications can provide WSUD benefits in terms of potable water use. Stormwater runoff can be harvested for local landscape use, creating ‘self watering’ landscape features and reducing mains water use for irrigation, a key consideration in achieving urban greening in times of water restrictions. Stormwater reuse for trees can take a number of forms including: passive irrigation of tree pits during rainfall events; enhanced infiltration and soil moisture recharge; and active irrigation by providing a stored water source for later reuse.

8.4 Bioretention systems

8.4.1 Description

Bioretention systems (also known as bioremediation or biofiltration systems) are currently a popular streetscape scale application, as they can be scaled down to confined spaces, and can be adapted to a range of urban settings (Wettenhall 2006). They were initially introduced in the US to treat car park runoff, and can take a number of forms including bioretention swales or basins (also known as raingardens), and bioretention tree pits (Breen *et al.* 2004).

NOTE:
This figure is included on page 157 of the print copy of the thesis held in the University of Adelaide Library.

Figure 18: Typical bioretention system

Source: Somes & Crosby (2007) p.2.

In a typical installation, as illustrated in Figure 18, stormwater runoff is diverted from the kerb into an extended detention basin with a depth of approximately 200-400 mm below footpath level, with any excess flow diverted to an outflow connected to the main stormwater system. Stormwater is then filtered through a vegetated soil media. Pollutants are removed initially by sedimentation in the extended detention zone, then by filtration through the prescribed soil media, and biological uptake of nutrients and other contaminants by plant roots. The filtered runoff is then collected in perforated underdrain pipes and returned to the main stormwater system for discharge, or to an underground storage for later reuse. As the undedrain typically connects to the existing stormwater system, the depth of the existing stormwater system can act as a design constraint limiting the depth of the underdrain and filter media. Alternatively the filtered stormwater can be allowed to percolate into the local groundwater (FAWB 2008). Bioretention basins may be contained, or lined with geotextile, if not intended to function by percolation into the surrounding soil.

Early Australian designs were not intended to function as infiltration systems, but were ‘closed’ systems with the main pathway of treated stormwater back into the conventional stormwater system, rather than to groundwater, and loss of runoff was mainly due to evapotranspiration and maintaining moisture levels in the soil media to provide a growing media for vegetation (City of Melbourne 2005). The current emphasis is on systems that promote groundwater recharge through exfiltration, a less costly option to fully engineered systems connected back into conventional stormwater infrastructure (FAWB 2008). However some form of underdrainage may still be required to prevent water logging of root systems (Craul 1992).

Bioretention systems include a temporary ponding zone over the soil media (200-400 mm below surrounding surface level) as an extended detention zone, which provides additional treatment by sedimentation, as well as increasing the stormwater capacity of the installation. Bioretention systems also typically include some form of high flow by-pass, to capture the most contaminated ‘first flush’ during rainfall events, and divert excess capacity flow to the main stormwater system. This may take the form of a diversion at the kerb inlet, or an overflow pipe within the storage basin, raised above the top of the soil media, to maintain storage.

Vegetation plays a significant role in bioretention systems. It enhances the pollutant removal function of the filter media in a number of ways: through a combination of physical, chemical and biological processes. It also maintains porosity of the filter media, with root growth continuously creating channels that maintain hydraulic conductivity. An additional function is in reducing erosion of the filter media. Plants also contribute to aesthetics and visual interest. The most commonly used plants are grasses and sedges such as *Dianella*, *Ficinea*, *Carex* and *Juncus* species (Breen *et al.* 2004). Plants which occur naturally on sandy soils, and which can survive periods of both inundation and drought, are preferred to the more aquatic species, as the systems are not continuously wet (the extent of drying depending on the local climatic regime and length of periods without rainfall). Non-aquatic species also act as indicators of system failure due to clogging of the soil media (Somes & Crosby 2007). A range of trees have also been used in bioretention installations, and the water treatment capacity of species including Plane trees (*Platanus orientalis*), Spotted gums (*Corymbia maculata*) and Weeping Lillypilly (*Waterhousia floribunda*) have been tested in experimental trials (Breen *et al.* 2004; Denman 2006).

Treatment occurs both during rain events and during the inter-event period. Pollutant removal during the rain event is by: sedimentation of litter, coarse particles and metals in the extended detention zone; filtration of fine sediments and colloidal particles by the filter media; and nutrient uptake by bio-films. Inter-event processes include: nutrient adsorption and pollutant decomposition by soil bacteria; and adsorption of metals and nutrients by filter particles (Somes & Crosby 2007). The wetting and drying phases are also important for both treatment effectiveness, and plant health (Breen *et al.* 2004).

Bioretention systems require an appropriate filter media, with a trade-off between the need for sufficient flow through the soil (high hydraulic conductivity), and retention of sufficient water to support plant growth (low hydraulic conductivity). Typically sandy loams are most suitable, however specialized soil media can also be specified, usually comprising a number of layers (for example mulch, filter and drainage layers). A number of soil specifications for Australian bioretention have recently been developed (FAWB 2007).

Bioretention tree pits

Bioretention tree pits, as shown in Figure 19, are a specialized form of bioretention system, involving the redesign of tree root-zone environments as stormwater treatment systems, which allow the incorporation of stormwater management into the most confined streetscape settings. Trees are grown in a suitable permeable media, with stormwater entering an extended detention zone, then percolating through the trees rhizosphere where it is treated by a combination of physical, biological and chemical processes, then to an underdrainage system collecting filtered runoff. The surface area, or number of tree pits in a street, will be determined by water treatment criteria, and tree spacing requirements (Breen *et al.* 2004). Sizing of bioretention and other stormwater treatment systems for a particular catchment can be undertaken using MUSIC (*Model for Urban Stormwater Improvement Conceptualization*) software developed by the Cooperative Research Centre for Catchment Hydrology (http://www.toolkit.net.au/music).

Figure 19: Typical bioretention tree pit concept

Source: Breen, Denman *et al.* (2004) p.702.

The main limitations on the use of street trees as stormwater management systems appear to be conflicts with underground services and infrastructure in retrofit situations, and long term tree health. The latter, involving stormwater treatment, soil characteristics and horticultural requirements of different tree species, has recently been investigated in Victoria at both Monash University and Burnley College of Melbourne University (Breen *et al.* 2004; Denman 2006; FAWB 2008).

Proof of concept

The Facility for Advancing Water Biofiltration (FAWB) was formed in 2005 as a joint venture between the Institution for Sustainable Water Resources at Monash University, and the consulting firm EDAW Australia (formerly Ecological Engineering). FAWB's mission was to provide 'proof of concept' by developing and field-testing a range of biofilter systems that could be applied to specific market based needs (FAWB 2008). These were also published in 2009 as *Stormwater Filtration Systems: adoption guidelines* (FAWB 2009). A program of research was undertaken between 2005 and 2008. One project (Technology), aimed to develop biofilter technology to overcome any technical barriers to adoption, and comprised three programs: vegetation trials; laboratory filter column experiments; and biofilter optimization for stormwater reuse. Another project (Demonstration and Testing), involved field trials of bioretention systems in Melbourne, Brisbane and Sydney to demonstrate the capability of multi-functional designs. Key findings were:

a) Two recommended biofilter designs: a standard design, shown in Figure 20; and a design with a submerged zone, shown in Figure 21.

NOTE:
This figure is included on page 161 of the print copy of the thesis held in the University of Adelaide Library.

Figure 20: Standard bioretention system (unlined)

Source: FAWB (2009) p.24.

NOTE:
This figure is included on page 161 of the print copy of the thesis held in the University of Adelaide Library.

Figure 21: Biofiltration system (unlined) with submerged zone

Source: FAWB (2009) p.35.

b) A 450 mm deep permanently submerged zone containing a carbon source such as hardwood chips was found to improve nitrate/nitrite removal. An important benefit of this permanently submerged zone is to support plant survival during extended dry periods. It was also recommended that systems should be unlined to encourage exfiltration where conditions allow, as reduction in stormwater volume due to exfiltration translates into reduced pollutant loads entering the stormwater system.
c) In terms of hydrologic performance, biofiltration systems must be appropriately sized to their catchments. Hydraulic conductivity tends to drop immediately after construction, but recovers over time. Outflow peaks should be no more than 20% of inflows, and systems should be built to promote exfiltration where possible, to help restore catchment hydrology to its pre-development state. However, even fully lined systems will experience high water losses due to evapotranspiration.
d) In terms of treatment performance, properly designed biofiltration systems can reduce levels of total suspended solids (SS) by 90%), total phosphorous (TP) by 80%, nitrogen by 50%, and heavy metals by 60-90%. Treatment performance will be reduced if the system is small in size relevant to its catchment, with a sizing of around 2% of catchment giving satisfactory performance.
e) Updated soil filter media specifications were developed, especially hydraulic conductivity. Guidelines were also developed for vegetation selection, with a marked variation in pollutant removal between different species (especially heavy metals). The valuable role of large tree roots in maintaining soil porosity was also noted.
f) Construction and maintenance issues were also addressed. Effective communication between designers and contractors is essential to ensuring quality control. Maintenance requirements are high during the establishment phase, but reduce significantly as vegetation matures, and initial dense planting can help minimize weed growth.

Design considerations

Bioretention systems applications can be integrated into the design of new streetscapes, or ‘retrofitted’ into existing streets. They offer opportunities for innovative and creative design solutions, and considerable design flexibility, being adaptable to many scales and spatial configurations. Streetscape scale applications, however, do present a number of urban and landscape design challenges not faced in larger scale applications.

First the design must meet functional performance requirements in terms of stormwater treatment, requiring an appropriate footprint and filter depth for pollutant removal. The approach typically involves defining the catchment and its impervious nature, determining the required footprint from a bioretention sizing curve, and evaluating interactions with the surrounding urban environment. Studies have derived relationships between pollution removal performance to the ratio of surface area to catchment area, and the basic processes remain unchanged regardless of scale (Lloyd *et al.* 2002).

Second is the need to adapt the design to a confined space. Installations may be retrofitted into established streetscapes with a range of constraints and competing demands for space, both above and below ground. Above ground, they must compete for space with footpaths, existing street trees and driveways. Below ground they will interact with a range of underground services, including stormwater infrastructure, gas, telecommunications, electricity, water and sewer mains. Installation may require the relocation of underground services. Bioretention systems will also often need to be linked with existing drainage infrastructure. The invert level of the drainage system will limit filtration media depth and underdrain level. Installations may be integrated with other streetscape elements to reduce their footprint, such as traffic calming devices or street tree pits. Bioretention systems are particularly suited to streetscape applications as they achieve higher pollutant load reduction in a smaller footprint than other measures, and bioretention tree pits can have an even smaller footprint (Wettenhall 2006).

The third consideration involves interaction with activities in the street, including both pedestrian and vehicular traffic. Bioretention systems should be sited to minimize potential conflicts, which may be damaging to their functioning and aesthetics. Designs should also be sufficiently durable to minimize deliberate and accidental damage, and also minimize long term maintenance costs.
A fourth consideration relates to public safety and liability issues, especially the presence of trip hazards in public streets. Bioretention systems require an extended detention zone with a depth up to 400 mm below footpath level, creating a potential tripping hazard. The grade change can be addressed in a number of ways, depending on the availability of space, from sloped or stepped surfaces to a vertical edge with some form of fencing. In the case of street tree bioretention pits, the opening can be covered with some form of permeable grille.

The fifth consideration is aesthetics, and visual appeal is a significant factor in gaining community acceptance and support. It also contributes to the educative role of streetscape installations, which can enhance public awareness of the urban water cycle. Installations in highly urbanized settings may require a more formal, hard edged, geometrical design than those in suburban settings, where a more naturalistic design may be appropriate. Bioretention systems can also be creatively integrated into other streetscape elements such as public seating. Self irrigated landscape features also provide new planting opportunities to create ‘green streets’. A wide range of vegetation is available for planting allowing for creative planting designs. A high standard of detailing is also required, rather than the purely functional engineering detailing found in early installations. And there is a need for site specific design, with forms, materials and plants reinforcing local character and amenity.

In conclusion, successful installations can ‘value add’ to the streetscape in terms of function, aesthetics and ecological sustainability. Successful design outcomes require collaboration between engineering, urban and landscape, design and environmental disciplines. Site specific design should respond to local context and involve a creative response to site constraints.

8.4.2 Bioretention Case Studies

The following section provides an overview of recent streetscape scale bioretention installations in Australian cities, including both: retrofitting bioretention systems into existing streets; and incorporation of bioretention measures in integrated stormwater management systems in new large scale urban developments. Table 41 provides a summary of recent bioretention projects.

Table 41: Bioretention case studies

Council/authority	Location	Type
Victoria		
VicUrban	Lynbrook Estate	Treatment train
Kingston City Council	Fowler Street, Chelsea	Bioretention basin
	Stawell Street	Bioretention basin
	Brisbane Terrace	Bioretention basin
City of Yarra	Cremorne Street	Bioretention basin
	Napier, Kerr Streets	Bioretention basin
City of Melbourne	Little Bourke Street	Bioretention tree pit
	Acland Street	Bioretention tree pit
	Davisons Place	Raised bioretention basin
VicUrban Docklands	Bourke Street extension	Bioretention tree pit
	Batmans Hill Drive	Bioretention tree cell
	Batmans Hill Drive	Bioretention swale
	Docklands Point carpark	Bioretention basin
	Village Street	Bioretention basin
City of Stonnington	Glenferrie Road	Bioretention tree pit
	Orchard Street	Bioretention basin
	Henry Street	Bioretention tree pit
NSW		
City of Sydney	Darlinghurst Road	Bioretention tree pit
Landcom	Victoria Park	Bioretention swale
Kogarah	Belgrave Street	Bioretention tree pit
Ku-ring-gai	Normurra Avenue	Bioretention tree pit
Queensland		
Brisbane	Melbourne Street	Harvesting and reuse
South Australia		
Adelaide City Council	SA Museum	Bioretention trench
Source: Various sources.		

Metropolitan Melbourne

Melbourne is recognized as a leading city in urban stormwater quality management. WSUD best practices have become, if not mainstream then at least 'institutionalized' at the State and Local government levels. This process has benefited from a number of 'champions', including the state water authority, Melbourne Water, local Councils, such as the City of Kingston, and the consulting firm Ecological Engineering (now part of EDAW). The process began in the late 1980's to early 1990's with recognition of the impact of urban runoff, especially nitrogen loads, on the water quality of the Yarra River and Port Phillip Bay. Initiatives by Melbourne Water and others to improve the quality of runoff from the catchment included the development of Lynbrook Estate by Vic Urban in 1994. This was an innovative outer suburban demonstration project which included a 'treatment train' at streetscape scale, consisting of swales, bioretention systems and wetlands (Lloyd *et al.* 2002). Since then a number of innovative streetscape scale projects have been implemented in more highly urbanized settings. The 2005 *Stormwater Offsets Strategy* provides a mechanism for Melbourne Water to require developers to meet stormwater quality treatment objectives onsite or through contribution of an offset payment for works elsewhere in the catchment. Target objectives are to treat stormwater runoff to remove 80% of annual suspended solid load, 45% of total phosphorous, and 45% of total nitrogen loads. The 2006 *River Yarra Action Plan* recognized the environmental threat of stormwater to the Melbourne's creeks, rivers and bays, and allocated $10 million to implement new WSUD projects to the four lower Yarra River Councils (Brown & Clarke 2007).

Kingston City Council

Kingston City Council is recognized as a leading organization for advancing WSUD, including a number of early streetscape scale applications, installed as part of its innovative road reconstruction policy. Kingston has approximately 1,380 ha of road reserve, which annually produce approximately 1,500 tonnes of sediment and 25 tonnes of nutrient pollutants, most of which is discharged into Port Phillip Bay. Funding from the *Victorian Stormwater Action Program* in 1999/2000 was a catalyst for Kinston's involvement with raingardens (bioretention systems), with the construction of a trial project in Riviera Street in 2001. As of 2006, Council had installed 84 rain gardens in 11 streets spread across eight suburbs (West 2006). These include the design of new residential streets, retrofitting into existing streets during road reconstruction projects, incorporation in traffic calming treatments and design of new car parks. Due to its pioneering involvement in raingarden construction and long term management, Kingston Council has been able to review its constructed projects, learn from early mistakes, and modify existing installations. Key findings have included the need for community acceptance through appropriate design, resident education and high standards of long term maintenance 9Somes &Crosby 2007). Council has a strong focus on the critical need for consultation and public education to elicit community support for raingardens in residential streets.

Fowler Street Reconstruction, Chelsea, 2003/04

The reconstruction of a residential street in the suburb of Chelsea, provided the opportunity to incorporate bioretention basins into conventional road and drainage construction (Melbourne Water 2006c). Stormwater enters the basins, located in the verge and in kerb outstands via depressed kerb inlets. After filtration the stormwater flows to the conventional underground concrete pipe drainage system. Design constraints included narrow verges, existing street trees and extensive underground services. The bioretention basins were fitted around existing trees and services by constructing outstands in the parking lane. Residents were kept informed during the process, and interpretive signs erected. A subsequent review identified the need to better define and separate the raingardens and nature strips, to achieve better streetscape integration and improve maintenance (Somes & Crosby 2007).

Stawell Street Reconstruction 2004

This residential street's wide nature strips, with a small cross fall, provided the opportunity to incorporate WSUD measures (Melbourne Water 2006b). Bioretention basins were constructed between existing street trees and driveways, with runoff entering via a gap in the kerb. The basins were designed to treat frequent rain events, and once a basin has filled, additional flow by-passes to the next basin. Conventional side entry pits collect bypass flow not diverted into any basins, during high flow events. The basins were designed to fit into the streetscape of grassed nature strips and mature street trees, with basins varying in size to accommodate existing trees. Importantly, the underground stormwater pipes in the street were located so that the junction pits could be converted to conventional side entry pits in the event of bioretention basin failure. A subsequent review considered the raingardens to be well designed, and well delineated with defined concrete edging and stone mulch (Somes & Crosby 2007).

Brisbane Terrace Reconstruction 2004

Road narrowing devices, in the form of kerb outstands, were installed in Brisbane Terrace in response to safety concerns for the school in the street (Melbourne Water 2006a). The opportunity to implement WSUD was taken by incorporating raingardens in these traffic calming devices. Runoff is directed into the raingarden, with overflow of excess capacity back onto the downstream channel. The heavily planted vegetation has thrived, creating a green landscape appreciated by residents. The treatment appears to be successful as it utilizes an area which would typically be planted, and is therefore acceptable to local residents. A subsequent review considered the raingardens to reflect best practice and were well incorporated into the streetscape, including a multifunctional role as part of traffic calming measures (Somes & Crosby 2007).

Inner Melbourne Councils

City of Yarra

Melbourne Water, in partnership with inner Melbourne councils, has developed a number of streetscape scale demonstration projects aimed at improving the health of the Yarra River (City of Yarra 2006).The City of Yarra has developed a Water Action Plan aimed at sustainable water management, and Water Sensitive Urban Design Guidelines.

Cremorne Street Reconstruction 2003

Cremorne Street, Richmond, is the first, well publicized example of a streetscape scale WSUD application in a highly built up commercial/industrial area, with heavy vehicular traffic flows (Melbourne Water 2007a). The project was jointly funded by Yarra City Council with a matching Victorian Stormwater Action Program grant. 29 bioretention basins were built as footpath outstands into the parking lane. Stormwater enters through gaps in the kerb, is filtered, and then returned to the conventional underground stormwater pipe system. Rocks are placed at the kerb entry points to distribute flows and prevent erosion. A high flow by-pass drainage pit, connected to the existing underground drain, is located in each basin, raised 50-100mm above the soil media base, but lower than the kerb entry point. Being a pilot project, a conservative design approach was adopted, to reduce flooding risk, with the bluestone paved footpath level well above soil level in the basin. The public safety issue was resolved with a steel post and wire fence. Interpretive signage was also installed. The fences, however, have been subject to both deliberate and accidental damage, reducing the aesthetic values of the streetscape. A subsequent review of the project found that the edge treatment should be reviewed in future projects, with the use of fences an unsatisfactory solution due to ongoing maintenance requirements. Lack of ephemeral storage was also an issue due to sedimentation (Somes & Crosby 2007).

Napier-Kerr Street Raingarden

The intersection of Napier and Kerr Streets, Fitzroy, was upgraded as part of Council's ongoing streetscape renewal program. Footpaths, road surfaces and drainage are renewed in an approximate 75 year cycle for a typical suburb, and 35-40 years for inner city suburbs. This provides the opportunity to retrofit WSUD measures into the built environment during asset renewal (City of Yarra 2006). At the intersection of Napier and Kerr Streets, use was made of the limited space available with bioretention raingardens integrated into traffic management measures, to both enhance the streetscape and provide stormwater treatment of road runoff (Melbourne Water 2009b).

City of Melbourne

In 2005 the City of Melbourne produced its *Water Sensitive Urban Design Guidelines* which addressed best practices and opportunities within the City. A number of demonstration projects have been implemented in partnership with Melbourne Water, including bioretention tree pits in Little Bourke Street in the CBD, at Acland Street in South Yarra, and a raised raingarden in Davisons Place, a narrow CBD laneway (City of Melbourne 2007).

Little Bourke Street Rain Garden Tree Pits 2006

Little Bourke Street is one of the narrower 'Little' streets in the commercial heart of the Melbourne CBD grid. It is significant as the first example of a WSUD application in a highly urbanized city centre (Melbourne Water 2007b). As well as meeting engineering and environmental requirements, the project faced the challenges of integrating the design into the infrastructure and functioning of the street, and of meeting the high standards of aesthetics required in the Melbourne CBD. The project was undertaken within a framework of consultation with traders and the local community. Tree pits, planted with *Waterhousia floribunda* (Weeping Lillypilly) were located in the footpath. Stormwater enters via a steel inlet grate in the water table, then into a deep extended detention zone, and after biofiltration is returned to the underground stormwater system. The tree pits are covered with heavy duty bluestone paving covers, hinged to allow opening to remove accumulated litter, with the tree pits also acting as litter traps. The design is also intended to encourage local traders to reduce cigarette butts and other litter. Challenges implementing the project involved relocation of underground services, and achieving the required levels to connect with the existing stormwater system.

Acland Street South Yarra 2007

Melbourne City Council's street tree managers have now adopted a more holistic approach to the greening of the city, aiming to incorporate a WSUD 'layer' into its street tree planting projects, to achieve water quality objectives, while at the same time reducing watering requirements for trees in a time of water restrictions. The process commenced with the upgrade of Acland Street, a residential street in South Yarra, (Melbourne Water 2008a). Street tree pits have been relocated from their existing footpath locations to the parking lane. Stormwater runoff enters the bioretention tree pits directly from the road, through a tree grate flush with the road surface, covering the extended detention zone. Each Japanese zelkova (*Zelkova serrata*) tree is protected from vehicular traffic by a pair of bollards.

Davisons Place Raingarden 2006

Davisons Place is a narrow, high walled CBD laneway with a hard surfaced, low amenity environment. The locality is changing from commercial to residential use and local residents sought opportunities to enhance the amenity of the street. The raingarden installed by Council comprises a raised planter bed at the end of the laneway, which collects stormwater from surrounding building roofs via downpipes and spreaders (Melbourne Water 2008b). Runoff is treated by biofiltration and returned to the stormwater system, at the same time irrigating the plantings including a single Weeping Lillypilly (*Waterhousia floribunda*) and underplantings. The raised bluestone wall is built at seating height, and the new environment provides a social gathering space for local residents. The Davisons Place rain garden demonstrates opportunities for innovative design in highly urbanized settings, to achieve both environmental and social benefits. The project was undertaken as a partnership between Melbourne Water, the City of Melbourne and local residents.

Docklands Precinct

The Docklands project comprises the redevelopment of the 200 ha Victoria Harbour precinct adjacent to the Melbourne CBD. The Docklands development was commenced in 2002 by the Docklands Authority, now VicUrban. Docklands is an example of innovation in incorporating WSUD practices into a large contemporary urban development at regional, precinct and local scales. With respect to stormwater management, this includes treatment of runoff to reduce pollutant loads to the Yarra River and Port Phillip Bay, and storage and reuse for the irrigation of public open spaces. Innovative streetscape applications have been developed as part of the wider stormwater management (Haycox 2004).

Key water management initiatives include the 3.5 ha Docklands Park, incorporating a system of free surface wetlands, which collect stormwater from adjacent urban developments for treatment and underground storage, then reuse for park irrigation. The wetlands also act as a contemporary urban landscape feature, incorporating public art installations and educative interpretive signage. Stormwater from the adjacent NAB building and courtyard is directed to a sediment basin then constructed wetland in the forecourt, designed in the form of an exclamation mark, creating a landscape feature as well as a water treatment system. It is then directed to Docklands Park for storage. These features provide WSUD ‘signature elements’, however two innovative infrastructure systems concealed below ground facilitate the storage and movement of water around the site. These comprise over 1.1 km of ‘Green Pipe’ and 580,000 litres of ‘Rainstore 3’ underground storage in Docklands Park (capable of withstanding 20 tonne loading), both constructed of locally recycled plastic.

Bourke Street extension

Street tree bioretention pits have been incorporated in the streetscape design of the extension of Bourke Street from the CBD into Docklands (Haycox 2004). Oriental plane (*Platanus orientalis*) trees are planted in bioretention pits which treat stormwater which is discharged into the Yarra

River. This was possibly the first Australian street tree stormwater treatment application (Breen *et al.* 2004).

Batman's Hill Drive

Bioretention systems have been integrated into the streetscape design of Batman's Hill Drive. Design objectives for Batman's Drive include upgrading the old arterial road (Footscray Road) to a high profile southern gateway to the Docklands, with a high quality vehicular, pedestrian and cycle environment (Haycox 2004). The road is lined on one side with a linear bioretention swale and on the other with individual bioretention tree pits (known as tree cells). The swale is planted with a row of *Angophora costata* (Apple myrtle) trees with under-plantings of native reeds and sedges. The tree pits are planted with individual *Angophora* trees and underplantings, and water flows directly from the road surface into the swale, which is protected from traffic by a row of bollards, Water also flows directly from the road surface into the tree pits, which are protected from traffic by semicircular raised seating structures. The raised seating: effectively defines the bioretention cell; takes up the grade change; provides footpath users with vehicular protection; and provides a visual and functional asset in the street. Treated stormwater is collected and discharged into the stormwater system. Heavy rainfall discharges directly into the main drainage system; however the bioretention system is designed to capture 90% of rainfall events.

Docklands Point Park carpark

Bioretention basins have been integrated into the design of the Docklands Point carpark, treating carpark runoff. The design incorporates a gabion basket to take up the 200mm grade change from the surrounding carpark, and each is planted with a tree and *Correa* species groundcover. The system is considered to be well designed both functionally and aesthetically, fitting well into the formal surrounding environment (Somes & Crosby 2007).

City of Stonnington

In 2005 the City of Stonnington adopted its *Sustainable Water Management Strategy* which requires Council to incorporate WSUD elements into all Council buildings and facilities to reduce potable water consumption and improve stormwater quality (City of Stonnington 2005). Council is currently undertaking a number of WSUD projects in partnership with Melbourne Water.

Glenferrie Road, Malvern upgrade

Bioretention tree pits, planted with Hill's Weeping fig (*Ficus hillii*) trees, have been incorporated in the streetscape upgrade of an intensively used shopping street with narrow footpaths. Each tree pit includes a grated kerb inlet and grated cover over the extended detention zone. A 1500 mm x 1500 mm precast suspended slab covers each tree pit providing a minimum 100 mm deep temporary ponding, and with a 500 mm x 500 mm tree trunk opening. A tree guard is also integrated into the design. Soil depth varies according to the depth of the stormwater connection. An issue during construction was installation of trees at the wrong depth required for an effective bioretention system.

Orchard Street Raingarden

WSUD elements have been incorporated into reconstruction works in suburban Orchard Street, including three raingardens, planted with low growing perennial plants, located in the footpath verge and corner buildouts. The choice of materials and plantings reflects the contemporary character of the surrounding architecture.

Henry Street Tree Pits

Bioretention tree pits were installed in a residential street in a partnership between Stonnington City Council and the Lower Yarra Stormwater program. The tree pits are installed in the parking lane covered with a metal tree grate, and enhance the amenity of the street by sustaining tree growth, while improving stormwater quality runoff (Melbourne Water 2009a).

New South Wales

Victoria Park

The Victoria Park project comprises the innovative redevelopment of 25 ha of former industrial land 3 km south of central Sydney. The low lying site comprises a former lagoon and Waterloo Swamp, which originally functioned as a natural wetland system, detaining and filtering water as it moved across the site. Victoria Park was developed by Landcom as its first inner-city project, with a clear innovation agenda. The first version of the master plan was prepared by Cox Richardson in 1998. A competition in 1999 for the detailed design of the public domain, however, recognized the need for a revised masterplan to better integrate water management into the design of the public domain, aimed at modifying the quantity and quality of stormwater runoff from the site, and to reduce flooding of the low lying site. The winning scheme by Hassel, in association with the Government Architects Office and environmental engineers Ecological Engineering, built on the inherent physical constraints of the site (including the flat to gently sloping site prone to flooding, a high water table and layers of sand and impermeable peat beds) using them as opportunities for design innovation.

An innovative 'community water management' system was developed for the whole site aimed at mimicking and reinterpreting the sites original water system, but in a highly urbanized context, so as to retain, filter and release stormwater in a controlled fashion. This involved the detention of stormwater on site, filtration to improve water quality, control of stormwater movement across the site, and the recycling of stormwater for use in the public domain. These processes have been successfully integrated into a high quality public domain of streets and open spaces.

The wide east-west streets were reconfigured to drain to a central median bioremediation swale, with permeable, saw tooth, kerbing. The swales were designed to treat the most contaminated first flush of stormwater. Partially cleansed water is held in an underground storage tank in Joynton Park and further cleansed by an electromagnetic filter for reuse on site. Flows in excess of a one-in-five-year event are captured by a system of inlets below pedestrian bridges over the swales, and then via underground pipes to a dished detention basin in the central park, which falls to a sedimentation basin and constructed wetland in a grove of paperbarks. The site's recreational open spaces have also been designed as detention basins to provide 'whole-of-site' flood attenuation. Water is pumped to a storage tank and reed bed integrated into Woolwash Park, a pocket park at the western entry to the development. Stormwater is also recycled for irrigation of public parks, and to operate a public art installation in the central park. The pumping system also draws irrigation water from the aquifer during low rainfall periods (Werwick 2004). The success of the project is considered to be the result of a strong collaboration between the developer, designers, artists, engineers and ecologists. The project has become a benchmark for inner urban redevelopment, achieving both environmental outcomes and a high quality public domain through a community water management system (Evans 2003).

Darlinghurst Road Upgrade, Kings Cross

The upgrade of Darlinghurst Road in Kings Cross, by the Sydney City Council, included the installation of bioretention tree pits in the footpath, intended to help reduce stormwater pollution of nearby Sydney Harbour (City of Sydney 2005). A new tree grate system was developed for the 4000 mm x 1350 mm tree pits, which allowed the trees to be set down below footpath level, by creating a 'suspended pavement' over an extended detention zone. The system was designed to foster the long term viability of each tree, with the air gap between the soil surface and suspended slab providing soil aeration as well as extended detention of runoff. The system was also designed to accommodate space for trunk thickening without pavement damage. It also included a pre-treatment pit from the kerb inlet. The project was developed as a pilot program to be reviewed before application to other projects. Difficulties encountered included failure to achieve connection to the stormwater system in some instances. The project was significant in terms of developing an innovative technical system to allow better integration of bioretention pits into the streetscape, both functionally and visually, however it has not been adopted elsewhere in the city due to its complexity.

Ku-ring-gai Council-Normurra Avenue Street Tree Pits

Ku-ring-gai Council installed bioretention tree pits in North Turramurra as a pilot project for their installation in its other six commercial centres (Ku-ring-gai Council 2006). The tree pits capture roof and carpark runoff from a 100 percent impervious catchment. The project aims included enhanced biodiversity and opportunities to integrate public art into the streetscape, as well as flow control and water quality improvement. The 3 m x 6 m tree pits are installed in the footpath, with the lowered surface (approximately 200 mm below road level) protected on three sides by a 500 mm high safety wall, with water entering via a kerb inlet and a 150 mm pipe connected to the nearby carpark.

Kogarah Council-Belgrave Street Low Flow Filtration and Reuse Project.

Kogarah Council developed a 'low flow filtration and reuse system' to treat and reuse stormwater in Belgrave Street, to complement the sustainable design of adjacent Kogarah Square (Kogorah Council 2002; Kogarah Council 2003). The 'filtration pits' consist of 600 mm x 600 mm precast concrete pits, with a 200 mm sand bed on a filter fabric over a 100 mm gravel layer of washed 20 mm aggregate. Each pit holds 108 litres prior to discharge. Stormwater from the road passes through the filters and then to adjacent linear garden beds via 100 mm diameter perforated pipes. Major flow events are redirected to the main drainage system via an overflow pipe. The prototype inlet consists of a 50 mm x 200 mm galvanized RHS inlet with 25 mm deep slots in the adjacent water table to direct low flows to the inlet. The pit also incorporates a trash basket at the inlet.

Brisbane

Melbourne Street Upgrade

A stormwater harvesting system has been incorporated in part of the Melbourne Street 'subtropical boulevard' entry to the Brisbane CBD. Stormwater runoff enters through a kerb inlet that filters rubbish, into a filtration pit that filters sediments, and then filters through the garden bed to a collection pipe and into an underground store with a pump to irrigate planting beds during dry periods.

Adelaide

South Australian Museum Forecourt Redevelopment

The South Australian Museum forecourt occupies a high profile site on North Terrace, Adelaide's cultural boulevard. The forecourt was redeveloped concurrently with the broader streetscape upgrade of adjacent North Terrace, in collaboration between the project landscape architects and urban designers, Taylor Culitty Lethlean, environmental engineers, Ecological Engineering, civil and structural engineers and irrigation designers. A water management system was conceived as an integral part of the redevelopment of the Museum forecourt (Allison & Taylor 2004). An objective of the redevelopment was to showcase the Museum's commitment to ecologically sustainable development, especially the concept of water harvesting, treatment and reuse. A bioretention swale was installed to treat runoff from the forecourt and surrounding impervious surfaces, which is then stored below the adjacent lawn for irrigation reuse. The bioretention swale was designed as a concrete shell to prevent infiltration effecting adjacent heritage buildings, with a 250 mm deep ponding zone. The concrete edging also provides the base for integrated seating.

8.4.3 Passive street tree irrigation

In response to issues of drought and landscape irrigation restrictions, a number of authorities have explored techniques for the passive irrigation of street trees by capturing stormwater runoff from kerbs, or from roof runoff (Stein 2009). The primary objective of such systems is to support tree growth and survival, by increasing stormwater infiltration into the root zone of the tree, and also recharging the surrounding soil water reservoir and groundwater.

Pollutant removal and flow control may be the secondary benefits of such systems. In Adelaide David Lawry sees trees planted in verges as a new generation of linear 'wetlands' for the city. Assuming a tree can transpire 100 kl of water annually, 10,000 trees could take up at least 1 Gl of stormwater, reducing polluted stormwater flows to nearby Gulf St. Vincent, the equivalent of the volume diverted to the Parafield Stormwater Harvesting Facility (Lawry 2008). Such systems can also capture much of the most polluted 'first flush' of road runoff (Porch *et al.* 2003).

Johnson (2009 p.19) however, points out that

> *The capacity of soil to absorb and store water is a limiting factor on the design of infiltration systems.*

A benefit of trees and other vegetation is their ability to enhance the storage capacity of the soil. They may even increase their rate of water use as the availability of water at a site increases (Eamus *et al.* 2006). Therefore

> *Incorporating well vegetated stormwater infiltration infrastructure into streetscape design may therefore be an effective means of managing a considerable portion of all stormwater* (Johnson 2009 p.19).

Street tree roots can also cause damage to infrastructure by migrating to resource rich areas such as the zone adjacent to the kerb, or below footpath pavements. Another aim of passive irrigation may be to redirect tree root growth by controlling soil moisture levels, encouraging tree roots to grow in well watered verges (Porch *et al.* 2003). A number of authors have emphasized the detrimental effects on trees of excessive soil moisture in poorly drained situations, leading to waterlogging and decreased soil aeration (Craul 1992). This remains an issue in the design of stormwater harvesting installations. One option is the development of systems in which stormwater runoff can be stored, often underground, for later reuse via a pumped irrigation system. The harvested stormwater may then be applied in judicious quantities when needed, thus avoiding waterlogging problems (Roberts *et al.* 2006 p.443). Storage and reuse can also help overcome the problems of extended dry periods in climatic zones such as that of Adelaide, South Australia (Beecham 2009).

Passive irrigation case studies

Claremont Street, Urrbrae Stormwater Harvesting Trials 2003

The opportunity to harvest road runoff, clean it and reuse it to irrigate street trees, while also reducing infrastructure damage, was investigated in South Australian trials in suburban Claremont Street, Urrbrae. The trial was undertaken through a partnership of Transport SA, the City of Mitcham, TREENET and the Urban Water Resource Centre at UniSA (Porch *et al.* 2003). The system was designed to treat 'first flush' road runoff, which carries the highest concentration of pollutant loads. Three kerb and water table inlet designs were trialed: permeable paving installed in the water table; pervious resin bonded gravel (Terrabond™) installed in the water table, and; a modified side entry pit (SEP) directed to a receiving pit designed to capture and hold first flush runoff. In each instance the harvesting device also acted as a filtering device, except the modified SEP, which also has a separate collection and filter pit layered with geotextile fabric. Collected runoff was gravity fed by a pipe to a 5 m long, by 600 mm wide by 300 mm deep distribution trench, filled with free draining crushed stone, with a capacity of 270 litres (sized to hold first flush runoff). Stormwater then percolates through a geotextile layer to the surrounding soil. Once at capacity, the remaining runoff is directed to the main stormwater system. The systems were also designed for ease of installation and minimal maintenance. The project was intended to be monitored, for long term and seasonal performance, including a network of moisture probes, to determine the suitability of the designs for implementation elsewhere (Porch *et al.* 2003). Some monitoring has been undertaken, and while preliminary results indicate the systems have value they also raise a number of issues. The permeable paving and Terrrabond™ inlets became unserviceable within four months due to clogging by sediments. The system is being modified with a revised design for the stormwater inlets (Johnson 2007).

Doncaster Avenue, Colonel Light Gardens

Another recent project in South Australia at Colonel Light Gardens in the City of Mitcham, involved installation of aggregate filled trenches to assist stormwater management and the long term health of a significant avenue of River Red Gums (*Eucalyptus camaldulensis*). 'Tree friendly' engineering solutions were developed for the existing and proposed trees, assisted by local community support for the retention of the avenue of trees (Johnson 2007). The project was functioning well after two years, in terms of tree health, surface porosity and surface flow interception (Johnson 2009).

Dorset Avenue, Colonel Light Gardens

Another type of passive irrigation system was installed by the City of Mitcham in Dorset Avenue Colonel Light Gardens in a planting situation with a kerb and water table. A soakage trench was installed at a site where a single tree had been removed from a mature avenue of White cedars (*Melia azedarach*). A side entry pit was designed to feed a perforated soakage pipe installed in the trench. The trench was filled with crushed rock, the voids providing a storage capacity of approximately 2 kl before infiltration into the surrounding soil (Johnson 2009).

8.5 Porous paving

8.5.1 Porous surfaces

Impervious surfaces

The widespread paving of urban surfaces is a relatively recent phenomenon, beginning with the introduction of macadam in the 1880's. Today, impervious paving covers vast areas of the city, particularly roads and sealed car parks. More recently, increased urban densification has seen a further increase in impervious surfaces (Thompson & Sorvig 2008). Impermeable paving has been implicated in a range of environmental problems, reversing the natural water cycle in which rainwater infiltrates into the soil, thereby sustaining vegetation and replenishing soil water and aquifers (Hough 2004). Impervious surfaces reduce infiltration into the soil, reducing groundwater recharge, and increasing stormwater runoff. Increased runoff can lead to flooding and pollution of downstream waterways, as well as placing greater demands on established stormwater infrastructure. Thompson and Sorvig (2008) make the case for more porous 'soft surfaces' in urban areas, to increase infiltration rates and groundwater recharge, and to reduce pressure on stormwater drainage systems. Seattle landscape architect Richard Haag advocates his 'Theory of Softness' which states that 'no ground surface should be harder than is absolutely necessary for its function', as an alternative to the engineer's desire to compact and pave every piece of ground in sight (Thompson and Sorvig 2008 p.181). The same principle can be applied to permeability, that 'no ground should be more impervious than necessary' (Thompson & Sorvig 2008). Table 42 presents the infiltration rates of a number of common urban surfaces.

Table 42: Infiltration rates of rainfall through different urban surfaces.

NOTE:
This table is included on page 177 of the print copy of the thesis held in the University of Adelaide Library.

Source: Roberts *et al.* (2006) p.190.

Porous surface types

Porous (or pervious) surfaces comprise a whole family of different materials and treatments. A number of authors have categorized the different types of surfaces, as summarized in Table 43 (Ferguson 2005; Thompson & Sorvig 2008).

Table 43: Porous surface types

Family	Type
Bonded aggregates	Porous concrete
	Porous asphalt
	Resin bonded gravel
Contained aggregate	Plastic grids
	Poured concrete grids
	Hollow concrete units
Stabilized turf	Plastic or concrete grids
	Hollow units
	Fibre reinforced turf
Soft porous surfaces	Bark, mulch, etc.
	Rubber
Porous paving systems	Porous paving units
	Open joint blocks
Source: Adapted from Ferguson (2005) and Thompson & Sorvig (2008).	

Bonded aggregates include porous asphalt, porous concrete and resin bonded gravel. Concrete and asphalt can be mixed in a manner that creates voids in the mix which allow the entry of air and water. This can be achieved with a 'gap-graded' or 'no fines' mix in which smaller particles are excluded and the large uniform sized aggregate is bound together by the binding agent. The voids created by gap grading are approximately 15-25% (Margolis & Robinson 2007). Porous concrete comprises a no fines mix with Portland cement binding the angular stone aggregate. It is strong enough for pedestrian use, parking and some vehicular traffic. Porous asphalt is the same as conventional asphalt, with aggregate and a binder, but with a single size, no fines aggregate. It is used by engineers as a road surfacing over impervious pavements to rapidly remove water, but without the benefits of infiltration into the sub soil. Resin bonded aggregate, marketed as products such as Terrabond™, is installed as a porous, but lightly trafficable surface around trees in tree pits (http://www.sureset.co.uk/). A 45-90 cm aggregate bed may also be placed under porous surfaces to retain stormwater until it infiltrates into the soil. For example a structural soil bed has been installed under a porous asphalt carpark at Cornell University (Haffner *et al.* 2007). Porous aggregates may be more expensive than conventional aggregates, however the costs may be offset by the reduced demand for stormwater drainage infrastructure.

Contained aggregate comprises aggregate in plastic grids, poured concrete grids, and hollow concrete units that prevent compaction. Stabilized turf comprises turf in plastic or concrete grids, or hollow units (to transfer vehicle loads), or fibre reinforced turf. Stabilized turf has a history of use in car parks. It significantly increases infiltration, but the grass may not survive daily vehicle use. Other ‘soft’ porous surfaces can also be used including bark, mulch, rubber and other, often local, materials.

It is important to distinguish between the two different types of porous paving systems in which either: the concrete pavers themselves are porous; or open joint systems with porous joints between the impervious paving units. Open joint systems can be either: conventional pavers at wider spacings, or with lugs to create 2-5 mm joints; or specially manufactured pavers with drainage openings filled with aggregate. The latter provides the highest infiltration rates, with the openings filled with uniform 2-5 mm aggregate acting as ‘vertical drains’ (Shackel & Pearson 2005). Porous paving, combining structural stability with permeability, came of age with the publication of United States landscape architect Bruce Ferguson’s 2005 handbook *Porous Pavements* (Ferguson 2005), which documented the different systems to a level acceptable to engineers, regulators and clients.

Benefits of porous surfaces

Porous paving can have economic benefits by reducing the volume and timing of runoff, and therefore the demand for stormwater infrastructure, in terms of the extent of new systems and the continued use of existing systems. These benefits can be increased by including a subsurface reservoir in the design, as illustrated in Figure 22, which decreases the need for other retention facilities.

Figure 22: Typical permeable paving cross-section

Source: University of South Australia.

It has also been demonstrated that porous paving can play a role in water quality through pollutant removal from stormwater runoff, by assisting in biological decomposition of hydrocarbon contaminants (Anon 2002; James 2002). By modifying stormwater runoff flows, and water quality, porous paving can also help reduce the cost of complying with stormwater regulations. And by enhancing infiltration, porous paving can assist in recharging maintaining natural groundwater and aquifers.

Porous paving also creates opportunities to cool asphalt pavements, and thereby reduce the urban heat island effect, by planting shade trees, and increasing reflectivity (measured by albedo) to reduce heat absorption. Asphalt surfaces can be lightened with coloured stones, aggregate or fines. Cooler pavements may also have benefits for tree root systems (Thompson & Sorvig 2000).

One of the main benefits of porous paving is that of multiple use, and it can result in more efficient land use planning by combining stormwater management with other uses, such as car parking, as opposed to single use engineering installations, such as detention ponds. In particular, engineered ‘eco-paving’ systems, if properly designed, can have the same structural performance as conventional pavers.

Benefits of porous paving to trees

A number of authors refer to the potential benefits of porous paving to trees.

> *The benefit to trees of porous paving, lies in its ability to provide a healthy rooting habitat, contributing to tree longevity* (Frank 2009 p.2).

In highly urbanized settings, impervious surfaces combined with compacted soils, present trees with a hostile environment with limited groundwater recharge and poor gaseous exchange.

> *Conversely, porous paving that allows moisture infiltration and gaseous exchange to the underlying soil, provides an improved rooting environment similar to a natural soil surface. In combination with other 'tree friendly' technologies such as load bearing rooting media or structural soils, providing modified growing environments that includes the application of porous pavement systems will allow more successful urban landscapes to be developed; a landscape in which increased opportunities for tree planting are provided* (Frank 2009 p.2).

And according to Edwards and Gale 92004 p.124)

> *Porous paving will assist the tree roots so that they need not be dependent on capillary action to draw moisture from the water table.*

Edwards and Gale (2004) also conclude that, as the size of a tree pit is related to the water holding capacity of the soil, the porosity of the paving will affect the size of the tree pit required.

A recent study by Morgenroth and Buchan (2009), however, raised issues regarding the benefits of porous pavements for urban trees. Oriental plane (*Platanus orientalis*) trees showed improved growth under porous concrete compared with normal concrete. Soil moisture and aeration were similar under both types (wetter and less aerated than the open control), however the soil under the porous concrete was better aerated at depth. They concluded that, while soil moisture dynamics are different between porous and non-porous pavements, the differences are not significant, and if urban trees do benefit it is probably not as a consequence of aeration or soil moisture (Morgenroth & Buchan 2009). May (2007) however, interprets these findings as reinforcing the idea that placing a permeable pavement on 'normal' soil may not enhance tree performance due to poor aeration, and the use of well drained soils may be required to maximize the benefits of permeable paving.

It has also been shown that urban trees themselves can act as tools for increasing infiltration and groundwater recharge, if their roots can penetrate compacted soils and increase infiltration rates, with root paths acting as conduits for water (Barrens *et al.* 2008). It should be noted that vegetation may also be considered as a constraint on permeable paving installations. Decomposing leaves may be beneficial, as they lead to microbial activity and accelerated hydrocarbon removal, but can also lead to clogging. Current advice is not to plant trees close to porous paving (Shackel, *et al.* 2008).

8.5.2 Eco-paving systems

Introduction

The most significant advance in porous paving in recent years has been the development of fully engineered ‘eco-paving’ systems that have the same structural performance (including vehicular traffic loadings) as conventional pavers while providing stormwater management and pollution control.

Engineered porous paving systems have been widely adopted in the UK and northern Europe, principally as a flood mitigation technique to minimize the costs of devoting large areas of high priced land to stormwater retention ponds. It is also increasing in popularity in the United States, driven in part by Environmental Protection Agency’s (EPA) control on management of stormwater pollution. In Australia, however, there has traditionally been reluctance from government agencies and designers to adopt such technologies, with misconceptions about the load bearing abilities and. maintenance requirements of porous pavements, as well as reluctance by civil engineers to allow water in proximity to road bases. The increasing adoption of WSUD practices in Australia in recent years however, may provide the opportunity to for more widespread adoption of such technologies (Frank 2009).

Background

The ongoing development of permeable eco-paving (also known as PICP pervious interlocking concrete pavers) has been documented by key researchers at the University of New South Wales and the University of South Australia (Anon 2002; Beecham 2003; Shackel & Pearson 2003a; 2005; Beecham & Myers 2007; Shackel *et al.* 2008). In Australia and elsewhere, government authorities are imposing regulations to control runoff from new urban development’s (Shackel & Pearson 2003a). These include requirements for on-site retention, control or delay of runoff volumes and timing, control of discharge water quality, and control of the extent of impervious surfaces. Recently developed permeable paving systems known as ‘eco-pavements’ comprise a permeable surface overlying permeable base and sub-base materials (Shackel & Pearson 2003a). The surface is installed on an engineered base providing a viable alternative to conventional trafficable paving. The systems were first developed in Europe and have been used in Australia since about 1997 (Shackel & Pearson 2005).

In Europe it has been used primarily as a means of flood mitigation, which minimizes the high land costs of installing on-site retention ponds, by combining these functions with already required paving areas. This remains a strong motivator in Australia, where urban consolidation is placing increasing demands on existing stormwater infrastructure. It has also been more recently found that permeable paving can significantly trap, remove and treat stormwater pollutants 'at source'.

Research at the University of New South Wales since 1994 has focused on laboratory studies of the structural capacity and water infiltration properties of eco-pavements, and more recent field studies of water quality control (Shackel & Pearson 2003a). Recent laboratory and field studies at the University of South Australia Water Centre for Water Science and Systems, have emphasized pollution management. These show that eco-pavers have the structural stability of conventional pavements, and can also trap up to 90% of particulate matter (Anon 2002). Research at the University of South Australia is also currently investigating the reuse potential of stormwater harvested with porous pavements. Design and construction of a carpark-sized test of the concept model is complete, and research is being undertaken on the water quality effects of the storage mechanism. This investigation builds upon existing research within the centre which has studied the infiltration rate, structural properties, lifespan and physical filtration efficiency provided by permeable block paving (Beecham & Myers 2007).

C&M Brick Pty. Ltd. introduced Ecoloc™ permeable pavers into Australia in 1997, followed by Ecotrihex™ pavers (http://www.adbrimasonry.com.au/environmental/ecotrihex/default.aspx). In 2006 the Concrete Masonry Association of Australia commissioned the University of South Australia to develop new design software for permeable pavements called PERMPAVE™. This was released in 2007, and together with the LOCKPAVE™ software for conventional pavements, provides an integrated design approach for permeable paving (http://www.cmaa.com.au/html/TechInfo/TechInfoSaleDetail.html#LockpaveAnchor).

Uptake of permeable paving has previously been limited in Australia due to lack of awareness and conflict with

> *… long entrenched engineering beliefs that water must be kept out of pavements wherever possible because it will lead to unacceptable performance in service, or, indeed outright failure* (Shackel *et al.* 2008 p.1).

According to Beecham, permeable paving now forms part of the general infrastructure landscape considerations that need to be considered in WSUD (Beecham 2003).

Authorities have expressed concern about maintenance of permeable pavers, especially clogging. Experience has shown reduction in permeability over 5-10 years, however a beneficial aspect is that pollutants remain in the pavement and can be removed by sweeping. Tests have shown that infiltration capacity can be restored by removing and replacing the top 12-20 mm of drainage material (James 2002). In systems with rectangular openings this can be achieved with street sweeping equipment. In contrast pavers made of porous concrete material are difficult to clean.

Design

Permeable paving reverses the traditional engineering approach to pavement design, that pavements and water infiltration are mutually exclusive. With permeable paving systems the whole pavement profile is designed to capture and store water, including: the paver layer; the aggregate base; and the sub base. Three cross sections are generally considered for different site conditions: full infiltration, where the system is lined with porous geotextile fabric and water percolates into the subgrade; part infiltration, with geotextile fabric and a drainage pipe; and no infiltration, with an impervious liner and drainage pipe. The last design is appropriate for contaminated or saline sites, or where the water is to be extracted and used for another purpose. Figure 23 illustrates a design option with a storage layer.

NOTE:
This figure is included on page 183 of the print copy of the thesis held in the University of Adelaide Library.

Figure 23: Eco-paving system with storage layer

Source: C & M Brick Pty. Ltd. (2005)

Design using the PERMPAVE™ software involves design for three factors, structural capacity, water infiltration and retention, and pollution control. Permeable paving is designed to capture the most polluted 'first flush' of rainfall events. Design requirements for the three components in the profile (surface, base and sub base) include the following. Surfacing can be either porous surfaces or open jointed pavers. Porous surfaces may not permit rapid infiltration suited to Australian conditions, and may be more prone to clogging (Shackel & Pearson 2003a). Base course and sub-base should meet the criteria of: adequate storage capacity; load bearing capacity; contaminant removal and ability to prevent movement of fine between bedding, base, sub-base and sub-grade (Shackel & Pearson 2003a). Free draining, open graded granular base materials as used in conventional road construction may be used, excluding materials finer than 2 mm, and geofabric layers may be required to prevent migration of fines.

Applications

Eco paving has been applied widely in pedestrian and trafficked spaces in Europe and the United States (Shackel & Pearson 2005). Ecotrihex paving was installed in the pedestrian plaza at Homebush Bay for the Sydney 2000 Olympics, illustrated in Figure 24, in conjunction with structural soils (Horne 1988).

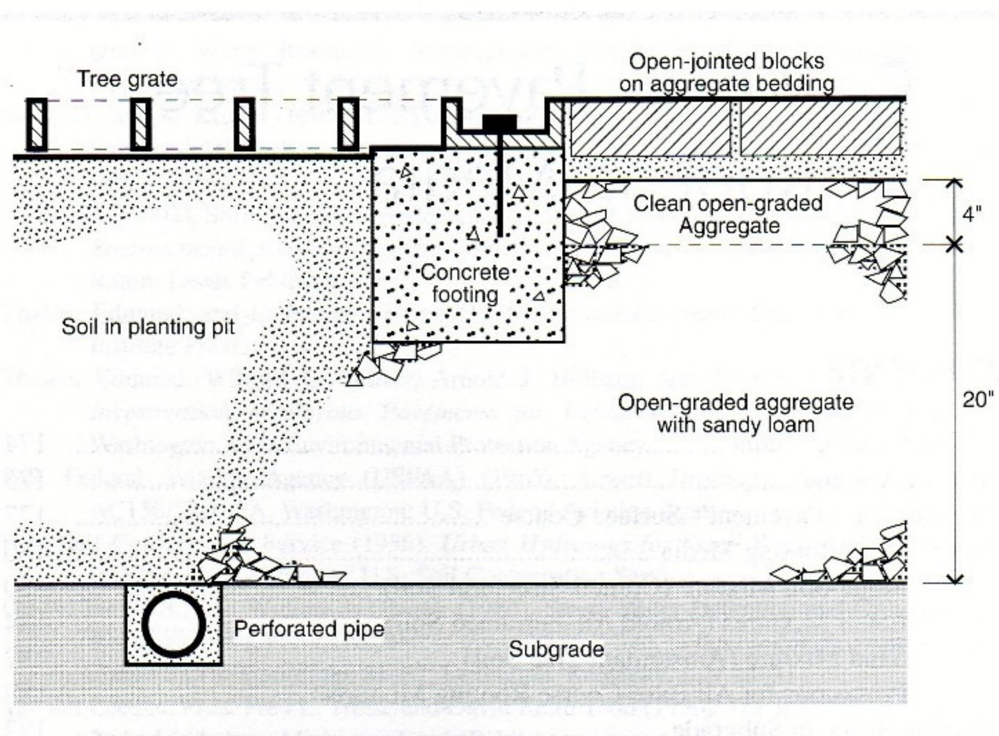

Figure 24: Eco-paving at Sydney 2000 Olympics site

Source: Ferguson (2005) p.172.

In 2002 Burnside Council in South Australia installed Boral Hydrapave pavers in a Linden Gardens car park, a WSUD demonstration site. The 300 m^2 car park collected infiltration runoff in an underground tank for irrigation of the adjacent mini wetland (Anon 2006). Eco-paving systems have also been installed in NSW at Smith Street Manly (Shackel & Pearson 2003a; C & M Brick Pty. Ltd. 2008a) and Moore Park Bus Station outside the Sydney Cricket Ground (C & M Brick Pty. Ltd.

2008b). Future eco-paving opportunities include trafficked parking lots, such as the hydropave installation being monitored by University of South Australia. Retrofitting of roads and installing PICP parking lanes is an important opportunity, as full road to road PICP is not usually necessary to achieve water control.

In the United States researchers at Virginia Tech, Cornell University and the University of California at Davis are investigating innovations in combining structural soils, shade trees and porous pavements to address stormwater and other environmental issues (Bassuk *et al.* 2005; Haffner *et al.* 2007; Day & Dickinson 2008; Xiao & McPherson 2008). In one test project, carpark stormwater runoff is directed to a structural soil bioswale planted with Oriental plane trees (*Platanus orientalis*), utilizing a Davis structural soil mix. In another porous asphalt has been installed in a carpark over a CU Soil reservoir to mitigate stormwater runoff, with linear tee pits cut into the porous asphalt surface and around the perimeter of the carpark (Haffner *et al.* 2007).

8.5.3 Eco-paving case studies

Smith Street Manly

The reconstruction of Smith Street, Manly is probably the best documented Australian eco-paving installation in which an old impervious asphalt road way was replaced with Ecoloc™ concrete segmental pavers (Shackel *et al.* 2003b; C & M Brick Pty. Ltd. 2008a) . It was also part of a wider innovative WSUD stormwater project. The project involved the retrofitting of a residential street built in 1900. The area has a sandy sub grade with high permeability allowing it to act as a sub grade to absorb water. The 100 year old stormwater system was a major constraint. Council elected to install a trafficable, permeable pavement. The pavement design profile comprised the following layers: 80 mm Ecoloc pavers; 30 mm -5 mm bedding course and jointing; 200 mm open graded granular basecourse; Bidim filter fabric; and 150 mm compacted subgrade.

It was estimated that the catchment area, including Smith Street was 45% impervious, and this was reduced to 20-25%. There was also a 60% reduction in runoff from the Smith Street sub-catchment, with surface flows reduced to 30% of expected flows in larger storm events. Benefits to Council included: reduced stormwater volume in an ageing pipe system; and reduced untreated outflow to Manly Beach. Benefits to residents included a revitalized streetscape, and decreased traffic speeds with segmental paving.

Moore Park Bus Station

The site comprises a set down area for buses in Moore Park outside the Sydney Cricket Ground. The original grassed site showed evidence of heavy use, and there was a need for a more durable surface to accommodate large pedestrian numbers and occasional vehicle loads. The site also had low natural fall restricting site drainage. There was also a need to protect an existing stand of nine mature state heritage listed Hills Weeping Fig (*Ficus hillii)* including aeration and moisture in the root zone extending beyond the canopy drip line (C & M Brick Pty. Ltd. 2008b).

The design comprised a build up pavement on existing subgrade to minimize root disturbance. The pavement design profile comprised the following layers; Ecotrihex pavers swept with 2-5 mm crushed aggregate; 25 mm bedding layer of 7 mm crushed aggregate; 50 mm thick drainage layer of 14 mm crushed aggregate, connected to two long soaking strips passing through the subgrade; 10 mm thick base of crushed recycled concrete; and the compacted subgrade.

Combining some infiltration through the base with the drainage layer leading to the infiltration trenches meant that a 20 year design storm could be accommodated without additional piped infrastructure. Substantial savings were therefore made on drainage costs by minimizing pipes. Occasional vacuuming is required to remove contaminants from the drainage voids to maintain permeability (every 5 years). The project also resulted in an attractive yet functional pavement.

8.6 Green Streets

Introduction

An ultimate aim of streetscape scale WSUD applications incorporating trees and other vegetation could be the design of ‘green streets’. Green streets are a growing practice in the United States, where streets are designed or reconfigured to accommodate stormwater runoff management and treatment, along with other sustainable design practices such as: traffic calming; pedestrian and cycle use; and the creation of attractive streetscapes. Green streets have been described by Thompson and Sorvig (2000) as ‘constructed ecological networks’. Two cities leading the way in green street design are: Portland Oregon; and Seattle (Vogel 2006).

Portland, Oregon

The City of Portland has a long history of comprehensive planning, including urban design, multi-modal public transport and green infrastructure systems. In Portland, a street that uses vegetated components to manage stormwater runoff at its source is referred to as a Green Street. Portland offers several examples of well designed green streets. The SW 12th Ave Green Street project in 2005 involved retrofitting a series of stormwater planters into an inner urban street. The retrofit project demonstrates how existing or new streets in highly urbanized areas can be designed to achieve both environmental benefits and be aesthetically and functionally integrated into the urban streetscape (ASLA 2006).

Seattle

Seattle has probably developed the most innovative green street solutions. Seattle Public Utilities has adopted a Natural Drainage System (NDS) strategy. This is based on Street Edge Alternative (SEA) neighbourhood streets, incorporating a variety of low impact development techniques to store, infiltrate and filter stormwater (City of Seattle 2008). These techniques were tested in SEA-Street No 1 where a conventional street was redesigned with a narrowed, curvilinear carriageway. A subsequent project, Pinehurst green grid, (covering twelve city blocks), involved redesigned the streets with an offset template, incorporating drainage swales in the widened side of the street. The next step in Seattle is to adapt NDS to more densely developed areas. A current project, 'Swale on Yale' applies NDS techniques to the redevelopment of high-density commercial area, incorporating four blocks of interconnected swales in a wide planting strip between street and footpath.

New York City

New York City has developed a set of *High Performance Infrastructure Guidelines*, which provides a roadmap for incorporating sustainable practices into the City's right-of-way infrastructure capital program (New York City Department of Design and Construction 2005). In guidelines such as these, street trees are formally recognized as a form of 'green infrastructure' delivering tangible benefits to the city.

Chicago

Chicago has approximately 3057 km of public alleys representing 1417 ha of impervious surfaces (City of Chicago nd). The Green Alley Program is a strategy for the sustainable redevelopment of the city's alleys based on five techniques: improved drainage through proper grading; permeable pavements; high albedo pavements; recycled construction materials; and dark sky compliant light fixtures. Four different approaches are adopted in the design of Green Alleys: Green Alley materials with conventional drainage; full alley infiltration using permeable pavements; centre alley infiltration using permeable pavements; and green pavement materials with a subsoil infiltration system. Green Alleys are part of Chicago Department of Transport's (CDOT) wider 'green infrastructure' program, which includes recycled construction materials, permeable pavements, recycled rubber sidewalks and other efforts. The program began as a pilot in 2006, and at 2008, more than 80 Green Alleys have been installed.

8.7 Conclusion

WSUD is a new paradigm for more sustainable management of the urban water cycle, aimed at better integrating the natural water cycle into urban areas at a range of scales. It has developed from the environmental consequences of past conventional engineering practices. Stormwater management, to control flows and water quality, is an important WSUD component. Stormwater management has evolved from conventional systems, to large scale ‘end of pipe’ treatments, to smaller scale applications that can treat stormwater ‘at source’, even at the streetscape scale. Such installations can also be of benefit to urban street trees, both directly and indirectly. Bioretention systems are one of the most popular and adaptable WSUD applications for urban streets, including bioretention tree pits. Bioretention systems are primarily designed to improve the quality of stormwater runoff returning to aquatic environments, but they can also have indirect benefits by providing supplementary water to urban trees. Stormwater can also be captured and redirected to urban tree root zones, increasing local infiltration and recharging soil moisture and aquifers, with direct benefits to trees. Increased areas of permeable surfaces is also a WSUD strategy beneficial to tree health, enhancing water infiltration and aeration. Permeable surfaces can take a number of forms, but have come of age with the recent development of eco-paving systems designed to meet engineering load bearing requirements, while providing stormwater management and pollutant removal services. Systems can be designed with a below ground storage reservoir, and incorporated into urban streets and car parks, making multiple use of valuable urban space. Permeable paving may also provide health benefits to urban trees, however the interactions between tree roots and permeable paving systems has not been investigated in detail. Table 44 provides a summary of key Water Sensitive Urban Design related strategies and practices identified in this section of the thesis.

Table 44: WSUD Practices

Strategy	Practice	Comment
Bioretention systems	Bioretention basin	In verge, in buildout
	Bioretention swale	Side of road, centre of road
	Bioretention tree pit	In parking lane, in footpath
	Bioretention trench	
Stormwater diversion	Permeable kerbs	
	Kerb inlet	
Passive irrigation	Tree pit in parking lane	
	Infiltration trench	
	Leaky well	
	Infiltration pipe	
Active irrigation	Subsurface storage with pump	
Permeable surfaces	Soft surfaces	Mulch etc.
	Bonded aggregates	Porous concrete, porous asphalt, resin bonded gravel
	Contained aggregate	
	Stabilized turf	
Porous paving systems	Porous pavers	
	Open jointed blocks	Conventional pavers
	Eco-paving systems	Ecoloc, ecotrihex
	With storage layer	

9 Australian Capital Cities Study

9.1 Introduction

A study was undertaken of current ‘best practices’ in street tree planting and streetscape design in the Australian capital cities of Melbourne, Sydney, Brisbane and Perth. The study focussed on capital cities, and the central areas of capital cities, as examples of the most hostile and constrained environment in which to establish street trees.

Methodology

A qualitative, case study approach was adopted, in which a researcher explores an activity in depth. The case study is bounded by time, place and activity, and the researcher collects detailed information using a variety of data collection procedures (Stake 1995).

In this study data were collected through interviews with key arboricultural and urban design staff. Interviewees were all senior staff acknowledged as luminaries in the field of arboriculture, both locally and nationally. Interviews were conducted in the participant’s workplace. Site visits were also made with interviewees to key projects in each city, and recorded photographically.

Table 45: Capital city interview participants

City of Melbourne	City of Sydney	Brisbane City Council	City of Perth
Ian Shears (City Arborist)	Karen Sweeney (City Arborist)	Lyndal Plant (Principal Urban Forest Policy Officer)	David Hammer (Arboriculturist)
Rob Moore (Manager Urban Design)	Andy Clark (Contracts Coordinator Street Trees)	Scott Chaseling (Urban Designer)	Barbara Shipway (Senior Urban Designer)
Peter Hornidge (Senior Landscape Architect)	Adam Fowler (Senior Landscape Architect)		
Ralf Pfliederer (Water Sensitive Urban Designer)			
Mark Haycox (VicUrban, Senior Urban Designer Docklands)			

The study was the first stage of a wider mixed method strategy, and was intended to be exploratory in nature, aimed at identifying key issues which would be investigated in more depth in the following stages of the study.

Interviews were exploratory in nature, allowing participants to express their views on issues of concern to them, so were relatively unstructured. The following topics, however, were addressed in each interview.

- Local context
- Strategic policy ‘drivers’
- Urban tree policies
- Streetscape design policies
- Organisational structure and project delivery
- Current street tree issues
- Current street tree practices
- Examples of best practice projects

Data consisted of interview notes, site photographs and any documents supplied by the participant. The interview notes were transcribed into a summary text document for each city. This document was then forwarded to each participant to confirm that it was an accurate record of the interview, and inviting any comments or amendments.

As well as developing a case study report for each city, comparisons were also made between the different cities. This included the preparation of tables comparing key variables. As is the nature of qualitative research, a number of themes emerged from the data, some specific to a particular city, and some common to all cities. These are summarized in the conclusion to this chapter.

Capital city profiles

The following Table 46 presents a ‘snapshot’ of some of the key characteristics of each of the case study cities.

Table 46: Capital city profiles

	Melbourne	**Sydney**	**Brisbane**	**Perth**
Settlement date	1837	1788	1825	1829
Area (km^2)	27.6	26.15	1367 (metro. area)	8.75
Population (2007)	86,000	169,000	1,007,900	13,500
Climatic zone	Cool temperate	Warm temperate	Humid subtropical	Hot temperate
Annual rainfall (mm)	661	1220	1189	869
Approx. annual evaporation (mm) (approx.)	1500	2000	1700	2000
Source: Australian Bureau of Statistics (2009), Bureau of Meteorology (2009). Population refers to the capital city local government area.				

9.2 City of Melbourne

9.2.1 Introduction

The following meetings were conducted. Meetings with Ian Shears, (City Arborist), and Rob Moore (Manager Urban Design), 12 April 2007. Meeting with Mark Haycox (Senior Urban Designer Docklands) VicUrban, 10 September 2007.Meeting with Ian Shears, (City Arborist), Peter Hornidge (Senior Landscape Architect) and Ralf Pfleiderer (Water Sensitive Urban Designer) 1 August 2008.

9.2.2 Local Context

NOTE:
This figure is included on page 191 of the print copy of the thesis held in the University of Adelaide Library.

Figure 25: Central Melbourne

The City of Melbourne (Figure 25) comprises the historic city centre on the Yarra River, and surrounding inner-suburbs. It covers a relatively small area of 37.6 square km with a resident population of around 86,000.

The City of Melbourne council is the administrative and tree management authority for the City. The statutory land development authority, VicUrban, however, is responsible for the planning of the Docklands development, which is being handed over to Council for management as each stage is completed. The city centre is characterized by a formal grid of wide streets, tree lined boulevards and formal parks. Melbourne has a distinctive formal grid derived from Hoddle's 1837 plan for the city. The grid comprises wide streets with narrower 'Little' streets between the main north-south streets (intended to provide rear access to properties fronting the main streets and continuous building frontages). A network of narrow lanes and arcades form a third street typology in the City. The city is also characterized by a number of significant boulevards, such as St Kilda Road, which act as gateways to the CBD.

While lacking an encircling belt of parklands, a number of formally landscaped parks contribute to the character of the city. The Yarra River also creates an open edge to the city, which has been alienated from public enjoyment by a range of uses, but is being reclaimed by recent initiatives including South Bank, Birrarung Marr and the Docklands redevelopment. Few open public spaces were allocated within the CBD grid itself, however a number have been recently created, including Melbourne Square and Federation Square.

9.2.3 Street tree management

Strategic level

Urban tree policies are seen to be driven by a number of policy 'layers'. The City has an ageing tree stock, with possibly 15,000 trees needing replacing in the next 10 years. Tree replacement is an ongoing issue. Changes occur to both trees and infrastructure over time. CBD streets do not last forever and require renewal.

Urban tree diversity is an issue, including the impacts of Dutch Elm disease (*Ophiostoma* spp.), Sycamore Lace Bug (Cor*ythocha ciliata*) on Plane trees (*Platanus* spp.) and *Phytophora* spp. also on Plane trees. There is no Dutch Elm disease in Melbourne at present, but planning is being undertaken for its possible future occurrence. The vector beetle has been present for decades, but there is no recorded instance of the fungus. Elm (*Ulmus* spp.) and Plane (*Platanus* spp.) trees comprise 20% of CBD trees which could potentially be lost to disease. Council is therefore trying to introduce new species into the CBD. In a period of water restrictions, watering of urban trees is a significant issue. Council has 15,000 trees in irrigated situations. The extent of these trees current root systems reflect past irrigation practices, with serious consequences if irrigation is turned off. Watering exemptions are provided for heritage situations, and Council is looking at new ways to deliver water to trees in the future.

Water Sensitive Urban Design (WSUD) has also created an additional tree policy layer. Melbourne Water part-funds the costs of WSUD projects, such as raingardens and bioretention tree pits, which contribute to improving the quality of stormwater runoff to the Yarra River and Port Phillip Bay. Such projects also have the secondary benefit of passively irrigating street trees.

Urban tree policies

A report prepared in 2002 provided a snapshot of the City's current urban tree situation, as a basis for planning in the following 10 years. Council has 55,000 street and park trees, including 6,500 Elms (mainly in city boulevards) and 5,500 Plane trees. Council also has an annual capital planting budget of $450,000. Council has a tree policy; however it is ten years old. Currently a set of *Precinct Policies* provide guidance for street tree planting in different parts of the City, especially when streets are restructured. For example, trees may be moved from footpaths to roads where there is more space available. There is no Precinct Policy document for the Melbourne CBD itself, where street tree plantings comprise mainly Elm and Plane trees.

Streetscape policies

For the past 20 years Council has been pursuing an innovative program to enhance pedestrian needs over vehicle needs in the central city. This has included the widening of footpaths in Swanston Street and Bourke Street and widening the south sides of the 'Little' east-west streets.

The process began in the mid 1980's with the urban design report *Grids and Greenery* (City of Melbourne 1987). In the mid 1990's the Danish urban designer, Jan Gehl measured pedestrian conditions and activity on the ground. He looked at urban amenity from all perspectives, including the role of vegetation. The study was replicated in 2004, showing measurable improvements in public and street life following the implementation of recommended streetscape improvements (City of Melbourne 2004). This has been a very useful tool in bidding for funding, as it includes firm data showing that people on ground, not cars, make the city more vibrant. The study also showed that more improvements were needed in the Southbank precinct.

The recent *Urban Design Strategy: Public Melbourne* (City of Melbourne 2006) follows on from the earlier *Grids and Greenery* (City of Melbourne 1987) most of which has been achieved. Council has policies for distinctive and cohesive suite of materials and streetscape elements throughout the CBD, including the consistent use of basalt footpath paving on a concrete slab base.

Council's urban design vision now also includes sustainability as a major policy driver, including the need to drought-proof cities. This includes developing new and cleverer ways to plant and water urban trees. Avoiding the problems created by past irrigation practices, which have resulted in shallow rooted trees susceptible to drought, instead of encouraging deeper rooted trees which can better survive drought, as in nature. This also means the last of the grassed medians and nature strips, with Council preferring under-planting of native species, using granitic sand as an alternative to turf, and using bioretention systems that provide passive irrigation.

Project delivery

Arboriculture and urban tree management is part of Council's Parks and Recreation unit, which in turn is part of a wider group which includes Urban Design (which operates at a strategic level with some design work), the Design Group (including architecture and landscape architecture) and Parks and Recreation. Key personnel from all disciplines work together when streets are being reconstructed, with monthly streetscape committee meetings. Standard streetscape and tree planting details are contained in Council's *Technotes* (http://www.melbourne.vic.gov.au/).

9.2.4 Current practices and issues

The following is a summary of the main street tree issues raised, and the related practices being adopted by Council.

Preferred tree species

Managing Council's heritage of street trees and avenues is a significant challenge. For heritage reasons, senescent trees are must be replaced with the same species, rather than more drought tolerant species. For example, senescent elms have been replaced with new Elms (*Ulmus* spp.). Historically the main tree species planted in streets, boulevards and parks have been European-style Plane (*Platanus* spp.) and Elm (*Ulmus* spp.) trees. It has been found that Plane trees are often too successful in city streets resulting in infrastructure conflicts. Planes are also perceived as having potential health issue, and their use in the Lygon Street restaurant strip in Carlton been debated with street traders. The design of the redeveloped Swanston Walk originally involved a native/exotic debate, but with Plane trees selected. Elms have been found to do well, with irrigation. Oaks (*Quercus* spp.) have also been found to be relatively drought tolerant.

In the narrower 'Little' streets of the CBD, Plane trees do not respond well, due to lower light levels, so *Waterhousia floribunda* (Weeping Lillypilly) is now the preferred species. *Melia azeradch* (Melia) has also proven a good tree, being relatively drought tolerant. Council is constantly trying to introduce new species. While aware of potential species, availability is limited by the nursery industry. Growers are therefore being commissioned to grow new species. Council tends to experiment with new species in small sites. For example in Franklin Street with the staged removal of *Populus simonnii* (Chinese poplar) and replacement with *Stenocarpus sinuatis* (Firewheel tree). Council experimented with the species first in North Melbourne.

The Kings Domain arboretum calls for diversity of trees, including Oaks (*Quercus* spp.) from wild seed collections. In Victoria Parade, unattractive Ash (*Fraxinus* spp.) and *Gleditsea tricanthos* (Honeylocust) trees are being replaced, on one side, with *Stenocarpus sinuatis* (Firewheel tree).

It is recognized that there is a need to consider which tree species will work best in different below ground conditions. The best way to do this is to observe how trees grow in their native forest. For example, tolerance of periodic flooding and inundation could be an indicator for selecting trees to be planted in bioretention tree pits. For example *Zelkova serrata* (Japanese Zelkova) trees have been planted in bioretention tree pits in Acland Street, South Yarra. Research is being undertaken into drought tolerance of *Tristaniopsis laurina* (Water gum) by Mike Looker. Cultivars have been propagated for specific form, colour etc. It is considered that the more recent emphasis on climate change and biodiversity will enrich the streetscape with new species in the future.

Streetscape design

It is generally considered desirable to plant as big a tree pit as possible, trees being the most significant greening element in the urban landscape. When planting trees Council tries to find the largest area available and widen the hole as much as possible. The current policy is to relocate trees from the footpath to the bitumen parking lane where possible, as a larger tree pit can be used. There are large amounts of centre road parking in Melbourne, with significant opportunities to enlarge the existing median tree islands.

The narrow city laneways are due for streetscape renewal, and are being looked at for redesign opportunities. Opportunities could be pursued for vertical greening, pleaching and espalier treatments appropriate in such confined spaces. The demand for bike lanes is an issue, often leading to the narrowing of central medians. The city's narrow 'Little' streets present the biggest design problems. For example Little Bourke Street, Little Collins Street and Flinders Lane. It would also be desirable to plant avenues of staggered species to facilitate future change management.

Tree pit surface

Resin bonded gravel (Terrabond™) is now being used on tree pit surfaces, due to problems with the previous use of granitic sand. Problems included disturbance by street sweeping machines onto footpaths and into stormwater drains. Council is using Terrabond™ of a similar colour to granitic sand. Stone size, texture and colour can be varied to suit the streetscape setting, for example a grey coloured mix in asphalt footpaths. These bonded products are, however, expensive and need dry conditions to install and a suitable base. Council is also looking at rubberized surfaces that can be lifted, to deal with tree root conflicts, similar to that used in Acland Street St Kilda.

Infrastructure

Council is very aware of the adage 'when the tree succeeds the infrastructure fails, when the infrastructure succeeds the tree fails'. Within the CBD bluestone paving is installed on a concrete slab, impacting on tree roots. Services have been found to be a major issue and limiting factor below ground. Clean-slate site are provided with trenching for combined services. The position of the tree relative to the kerb is a key consideration. Planting too close can result in damage to the tree and replacement of kerbs in streets, and paths in parks. Typically tree roots follow the verge (following the water gradient) and impact on bluestone kerbing, resulting in repair costs and tree damage. Roots also tend to go under footpaths and into private property, necessitating the installation of root barriers.

Water management

Water filled road barriers are being used to irrigate trees with imported water, for example the Elms (*Ulmus* spp.) in Birrarung Marr Park. Where possible trees should be grown in the same soil mix as the planting site, as in Acland Street South Yarra.

Water Sensitive Urban Design

WSUD is now seen as driving the design ethic in the city. Bioretention tree pits have been tied into broader streetscape projects which include widening footpaths on both sides of pedestrian streets, reducing car parking and increasing pedestrian space. WSUD has been focused into the broader project. Initial bioretention tree pits have cost $5-6,000 including design costs, and including $500 for the tree. The high cost of the hard structure around bioretention tree pits has become an issue. WSUD installations are also seen as having high maintenance costs. Connection of bioretention systems to existing stormwater infrastructure is also an added cost. In Bellair Street there is existing stormwater. In Acland Street a stormwater connection needed to be put in. In some older streets there is no stormwater system, which needs to be installed. After a first generation of engineered bioretention systems, Council is now looking at how to add value to tree pits with water retention, even if the tree pit is not connected to the stormwater system. Planning of WSUD installations uses the MUSIC program, which is based on historical rainfall data. This has now reduced though, with soils drying out. The current WSUD issues are the opportunities for passive irrigation, maintenance costs, and the difficulties of fitting raingardens into the streetscape. Sediment build-up from construction works has been an issue with the Docklands bioretention systems. The use of permeable paving in the CBD is an issue, with the City's urban design ethic requiring uniform bluestone pavers.

Implementation

There is a major need for community consultation during street reconstruction projects, and Council prepares sophisticated 3D computer simulations and presentations as tools to visually communicate the future outcomes of street improvement projects. Political support can be an issue, as Councilors are usually only there for 3-4 years. There are limited opportunities as no new streets are being built and street redevelopment opportunities are rare.

9.2.5 Melbourne reference projects

Earlier projects

Swanston Walk. Swanston Street, formerly the main north-south traffic artery through the Melbourne CBD, was converted to pedestrian and public transport use in 1992, and renamed Swanston Walk. Footpaths on both sides of the street were widened to 8.6 m, with a 2 m wide street furnishing zone adjacent to the kerb. Plane (*Platanus orientalis*) trees were planted in large tree pits, with granitic sand surfaces. Trams run down the centre of the 14 metre wide roadway. The project has been a great success in creating a pedestrianised boulevard in the centre of a major city. Maintenance issues with granitic sand have resulted in the tree pits being surfaced with resin bonded gravel matching the colour of granitic sand.

Recent and current projects

Swan Street (Olympic Boulevard). This was the first major streetscape remake. It included the removal of 55 elms (*Ulmus* spp.) declining due to infrastructure changes, and planting of 95 new trees at closer spacings.

Queen Victoria Site. Street tree planting includes a continuous trench with structural soil along Lonsdale Street and up Russell Street.

Victoria Parade. Unattractive *Fraxinus* (Ash) and *Gleditsea tricanthos* (Honey locust) trees are being replaced with *Stenocarpus sinuatis* (Firewheel tree).

Franklin Street. Involves the staged removal of *Populus simonii* (Chinese poplar) and replacement with *Stenocarpus sinuatis* (Firewheel tree).

Collins Street. There have been problems with street tree health, due to Council's policy of paving on a concrete slab base. Council's arborists have been working with its engineers on shallower profile pavements and larger tree pits.

Royal Lane. A narrow lane has been planted with *Waterhousia floribunda* (Weeping Lillypilly), using 5-7mm asphalt coloured Terrabond™ as a tree surround.

Fitzroy Gardens. Two new avenues of trees have been planted in the park. One replaced 14 declining Lombardy poplars (*Populus niagra* 'italica'), a poor urban tree, with 22 new trees. The other comprised a new avenue with no existing trees. These were the first new plantings in Fitzroy Gardens in 80 years, requiring major consultation.

City Gateway. *Stenocarpus sinuatis* (Firewheel tree) have been planted in a grouped pattern in the new city gateway landscaping at the northern end of Swanston Street.

Park Street South Yarra. A current design proposal, with sophisticated 'fly through' presentations to educate residents.

Water sensitive urban design projects

A number of streetscape scale WSUD projects have been undertaken recently by Council, with joint funding and technical input from Melbourne Water.

Acland Street, South Yarra. New *Zelkova serrata* (Japanese Zelkova) trees were planted in the parking lane on one side of the street only, replacing the existing trees which were located in the footpath. Trees are planted in bioretention pits. The soil mix in the tree pits is designed for filtration, so it is not possible to use trees with high Air Filled Porosity requirements. The *Zelkova* trees have been growing well, are hand watered, and staff report that they need 70% less water than other trees.

Little Bourke Street. *Waterhousia floribunda* (Weeping Lillypilly) have been planted in bioretention tree pits in the footpath, part funded by Melbourne Water. The tree pits also act as litter traps. The project involved some major relocation of underground services. Subsequent issues with the design included excessive litter entry at the opening in the tree grate, and vandalism damage in a highly trafficked area.

Davisons Lane. A bioretention system has been built into a raised planting bed at the end of a narrow CBD laneway, planted with a single *Waterhousia floribunda* (Weeping Lillypilly). The raingarden helps create greenery and amenity for residents in a hard surfaced urban setting.

Little Collins Street. A section of Little Collins Street was planted, on one side of the road, with *Waterhousia floribunda* (Weeping Lillypilly) in bioretention tree pits. These were similar to the Little Bourke Street tree pits but with a modified tree pit grate to reduce litter entry and to increase the trafficable space over the tree pit. Large tree guards were also installed, as a result of vandalism issues with the Little Bourke Street trees, integrated into the design of the tree pit grate. A similar tree guard was also retrofitted in Little Bourke Street.

Bellair Street Kensington. Bellair Street has Oriental plane trees (*Platanus orientalis*) located in the parking lane. The redevelopment of the street has created a rare opportunity to implement WSUD initiatives. WSUD tree pits will mimic the typical 2 m x 2 m street tree pit, but with sloping sides to allow for passive irrigation from stormwater runoff. This is an example of a move towards simpler and more economical WSUD initiatives with less engineering infrastructure. Bellair Street represented a rare street redevelopment opportunity in the City.

Harris Street North Melbourne. In Harris Street the existing street trees have distorted the kerb. A new street cross-section is being considered which would incorporate a number of WSUD measures. These include passive irrigation of existing and proposed trees. Consideration is being given to a permeable paving unit in the kerb and channel which can be cleaned by street sweeping machines. A linear soakage pit would be located behind the kerb, filled with aggregate. It is hoped that this will act as a passive root barrier reducing damage to the bluestone kerb. It is thought that the local clay based soil has the required infiltration capacity; however an overflow outlet to the stormwater system will still be required. A possible low maintenance kerb entry detail would be to remove one bluestone kerb unit and replace it with a new unit with holes in it.

Bullens Lane. A sand infiltration trench (without vegetation) has been installed in the centre drainage swale in Bullens Lane, a narrow rear service off Russell Street, with oil and other waste issues.

Pasley Street South Yarra. A current design proposal, part funded by Melbourne Water, based on a philosophy to decrease impervious surfaces and to catch and treat runoff with bioretention systems, creating a suitable environment for trees. Palsey Street is relatively flat and Council is looking at the possibility of an infiltration trench with permeable paving over.

Docklands precinct.

The Docklands precinct has been developed by VicUrban (with input from council), but management of the completed areas will be progressively handed over to Council. Actual design work has been undertaken by the project developers, within a design guideline framework, or in some cases, such as Docklands Park and Batman Hill, by VicUrban itself. Street tree planting in new residential areas and public space is aimed at place making. Street trees also play an important role in creating pedestrian amenity, especially in terms of wind reduction in an exposed waterfront setting. Tree planting has been guided by a seven year old tree strategy currently being updated. Street tree planting takes place at a number of levels.

a) The Melbourne CBD grid has been extended into the Docklands precinct with the extension of Bourke Street and Collins Street. The civic character of these streets has been maintained with planting of Plane (*Platanus orientalis*) trees to create a distinctive east-west theme.
b) Smaller streets and laneways create other layers with planting of distinctive a tree species such as Peppercorns (*Schinus aera* var *molle*), Araucarias (*Araucaria* spp.) and Chinese elms (*Fraxinus parvifolia*).
c) Plantings along the waterfront public spaces include palms, *Ficus*, and *Corymbia* species, with a distinctive use of grove planting and topiary.

The Docklands project has had a strong Water Sensitive Urban Design theme, and includes some of the first bioretention tree pits in Australia. Installations include the following:

Bourke Street Extension. Plane trees have been planted in bioretention tree pits in the Bourke Street extension, spaced 8 m apart in the footpath. This design was the first of its type in Australia, integrating bioretention tree pits into a dense urban environment. The tree pits filter stormwater which discharges to the Bourke Street culvert and eventually to the Yarra River.

Batman's Hill Precinct. The innovative bioretention cells in Batman Drive, are planted with *Angophora costata* (Apple myrtle) trees and integrated with public seating, represented the next generation of design. A linear bioretention swale on the opposite of Batman Drive also incorporates

Angophora trees. The swale drains directly from the road surface, defined by a row of bollards rather than a kerb.

Village Street Tree Pits. Village Street is lined with bioretention tree pits located in the parking lane, below road level, but without tree grates. Runoff is directed to a grated drain below road level between the tree pit and the kerb. It then enters the tree pit via a perforated subsoil drain around the tree. When the root ball becomes saturated, excess water enters the conventional stormwater system.

Collins Street Bridge

An avenue of Plane trees (*Platanus orientalis*) was also incorporated into the Collins Street extension bridge, designed on arboricultural principles, to provide each tree with 10 m^3 of soil volume in a continuous shared root trench.

9.2.6 Summary

Table 47 provides a summary of the different practices identified in the City of Melbourne case study.

Table 47: Melbourne Practices Summary

Practice	Reference project
Streetscape design	
Footpath widening-traffic lane removed both sides	Swanston Walk
Planting in parking lane	Acland Street
Planting one side of street only	Acland Street, 'Little' streets
Enlarged median tree islands	City wide
Group planting	City gateway
Vertical landscapes, pleaching, espalier	Proposal-narrow streets, laneways.
Below ground design	
Enlarged tree pits	Collins Street
Continuous trench-structural soil	Queen Victoria site
Containerized-above ground	Southbank, Bourke Street Mall
Containerized-below ground	Collins Street Bridge Docklands
Tree pit surface	
Granitic sand	CBD, Melbourne Square
Resin bonded gravel	CBD-Royal Lane, Collins Street, Swanston Street
Water management	
Bioretention tree pit-in footpath	Little Bourke Street, Little Collins Street, Bourke Street extension Docklands
Bioretention tree pit-in parking lane	Acland Street
Raised raingarden-roof runoff	Davisons lane
Bioretention tree pod with seating	Batman Drive Docklands
Bioretention swale	Batman Drive Docklands
Passive irrigation-tree in parking lane	Bellair Street
Passive irrigation-infiltration trench in verge	Harris Street (proposed)
Infiltration sand trench-unvegetated	Bullens lane
Pervious surfaces	Pasley Street (proposed)
Irrigation with water filled road barriers	Birrarung Marr
Infrastructure	
Shallow pavement profile	Collins Street (proposed)
Rubberized surfaces	Proposal
Tree species selection	
Shade tolerance (narrow streets)	*Waterhousia floribunda* (Weeping Lilypilly)
Periodic inundation tolerance (bioretention)	*Zelkova serrata* (Japanese Zelkova)
Source: Case study interviews.	

9.3 City of Sydney

9.3.1 Introduction

The following meetings were conducted. Meetings with Karen Sweeney, City Arborist, and Andy Clark, Contracts Coordinator Street Trees, City of Sydney, 19 April 2007. Meeting with Adam Fowler (Senior Landscape Architect) 20 November 2007.

9.3.2 Local context

NOTE:
This figure is included on page 202 of the print copy of the thesis held in the University of Adelaide Library.

Figure 26: Central Sydney

Sydney's urban form differs from that of most other Australian capital cities, growing in a relatively unplanned way from its origins as a penal settlement, rather than a consciously planned city. Sydney is Australia's oldest capital city. Growing out of the historic unplanned settlement of Sydney Cove, the Sydney CBD has winding narrow streets, compared with the formal grid of wide streets found in planned cities such as Melbourne. The relatively narrow streets and footpaths provide limited planting space. The narrow streets are also now lined with tall buildings, creating shading problems.

The central city is contained within a peninsula, bounded to the north and west by the waters of Sydney Harbour, and to the east by a belt of public parkland (Figure 26). The southern end of the city centre was later defined by the suburban and country rail terminus at Central Station. This physical containment has limited the ability of the centre to expand horizontally, with development pressures accommodated by increasing building heights. Public lands are a significant determinant of the urban form of Sydney, forming a containing band around the private land of the city. The irregular street grid is bordered by public spaces such as Hyde Park, the Domain and the Sydney Harbour foreshore, which comprise much of cities public domain.

Unlike some cities, Sydney lacks a particular urban space which symbolizes the city. This role is provided to some extent by the pedestrianised Martin Place (a public space in the commercial heart of the city with a symbolic focus at its western end around the Cenotaph) and the civic space of Sydney Square. The pedestrianised section of Pitt Street comprises the shopping focus, marked by the Centrepoint Tower, while Circular Quay remains the symbolic focus where the city meets the water, the site of first settlement and the monuments of the Sydney Harbour Bridge and Opera House.

Due to its history of development, central Sydney also lacks the wide planned boulevards found in other capital cities. Although relatively narrow and winding, George Street is recognised as the city's main street. Other important public streets include historic Macquarie Street and the pedestrianised Martin Place and Pitt Street Mall. There are approximately 25,000 trees in the City with some 5000 urban trees in the CBD. In 2005 some 743 trees were planted (in CBD and east, west of city) and in 2006 1500 were proposed in the southern area, 300 in northern area.

9.3.3 Street tree management

Strategic level

Trees are seen as essential or fundamental to urban projects, providing amenity, scale and shade. They are an investment in the future. Strategic planning occurs in a different division in Council. Council is undertaking a 2030 process: envisioning the city in 2030 and then working back to see which strategies need to be adopted to achieve that vision. The strategy talks about creating green-links, but it must be recognized that these streets have other uses also. Jan Gehl has also recently undertaken a public life study of the Sydney CBD, addressing a range of strategic public domain issues (Gehl 2008).

Urban tree policies

The City has a suite of tree management policies under the umbrella name *City of Sydney Tree Management Policies-Trees for a Living City* (http://www.cityofsydney.nsw.gov.au/Environment/TreeManagement/TreeManagementPolicies.asp) which are intended to provide tools for tree management and planning in the City of Sydney. These include the following:

- *Urban Tree Management Policy* (Volume 1)
- *Tree Preservation Order* (Volume 2)
- *Street Tree Master Plan* (Volume 3)
- *Significant Tree Register* (Volume 4)
- *Tree Management Plans for the 19th Century Parks*
    - *Hyde Park*
    - *Redfern Park*
    - *Observatory Hill Park*

A past history of poor species selection and planting practices underlay the need for the current *Street Tree Master Plan*. It addresses every street in the city, including existing trees, proposed trees and infill planting, and builds on the existing tree palette of the city. The *Street Tree Master Plan* (City of Sydney 2004) consists of a number of sections including the following:

- *Species Selection*-including tree selection criteria and design principles.
- *Precinct Plans*-nominating the tree palette and design objectives for each precinct.
- *Street Tree Master List*-nominates the tree species for every street.
- *Technical Guidelines*-includes tree set out, tree planting and surrounding details and specifications.
- *Appendices*-including tree data sheets and road classification lists.

The *Street Tree Master Plan* is considered a 'living document' and is reviewed and updated annually.

Streetscape policies

Current streetscape policies follow on from the initiatives leading up to the 2000 Sydney Olympics. This is based on a controlled palette of materials, including installation of granite paving throughout the CBD. Council also looks at opportunities to remove traffic lanes to enhance pedestrian amenity and to allow for separated bike lanes. In addition Council has commenced several projects to plant trees within the roadway/parking lane, including Redfern Street and William Street. In some streets there is a preference for 'borrowed landscape'. For example, street trees not planted in the streets around Hyde Park and Redfern Park.

Organizational structure

Design and delivery of specialized streetscape projects, such as capital works programs over $200,000 is undertaken by City Projects. Overall, City Projects is responsible for three programs: buildings, streetscapes and parks. Streetscapes and parks are undertaken by the City Projects landscape group. City Projects has two clients, the Parks Asset Manager for parks, the City Arborist for trees and an equivalent for streetscapes. Smaller planting projects that do not require major infrastructure changes are undertaken by the Tree Management Team, with capital works program valued at $1 million to $500,000 per annum depending on the scope of works.

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Arboriculture is part of City Services which is responsible for providing physical and community services. Arboriculture is in the Parks, Trees and Aquatic Facilities division of City Services. The Tree Management team develops all policies and strategies for tree management, undertakes all tree maintenance and provides all of Council's expert advice on tree management, including input to City Projects

Design details

The *Technical Guidelines* in the *Street Tree Master Plan* includes typical street tree planting details and specifications, including details for structural soils, suspended pavements and tree pit surface treatments (http://www.cityofsydney.nsw.gov.au/Council/documents/policies/StreetTreeManagement/StreetTreeManagementPolicy/MasterplanVolume3PartE.pdf).

9.3.4 Current practices and issues

The following is a summary of the main street tree issues raised, and the related practices being adopted by Council.

Preferred tree species

Extensive use is made of Plane (*Platanus orientalis*) trees in major city boulevards; however it is now necessary to consider the possible impact of Sycamore Lace Bug (*Corythuca ciliata*) on Plane tree populations.

There are difficulties in finding suitable trees for shaded streets, and Council is looking at advanced (3.5-4.0 metre high) palms as a replacement. In particular, a cabbage palm (*Livistonia australis*) theme has been adopted in the narrow, shaded streets leading down to Circular Quay, building on a theme established in Chifley Square and the foreshore promenade. Poplar (*Populus*) species have been found suitable in narrow, shaded streets in the CBD.

Ficus species are a feature of Sydney's parks, but are generally too large to be considered a suitable street tree. However Hills weeping fig (*Ficus hillii*) is being planted extensively by the Sydney Foreshore Authority in Pyrmont and Darling Harbour, as it provides 'instant effect' in redeveloped areas. *Waterhousia floribunda* (Weeping Lillypilly) and *Flindersia australis* (Crows Ash) are the preferred replacements for the Hill's Figs (*Ficus hillii*) within the streetscape environments.

Tree pit surfaces and installation

In the past, Council has used a detail with granite setts, preferred by Council's landscape architects, which has resulted in failure through settling. There are some differences between Council's design and arboricultural staff regarding planting details, of aesthetics versus functionality. The aesthetics of resin-bonded gravel in the granite paved urban streetscape has been questioned. Council is now using plain Terrabond™ without granite setts with the objective of greening the city, and tree unfriendly bases are being avoided. Shrinking of Terrabond™, used in tree surrounds, is also an issue. Installation of tree bases (Terrabond™ and decomposed granite) is delayed for 6-12 months to allow for soil settlement. This allows for improved water penetration during the increased maintenance period, and also reduces slumping of the Terrabond™ during soil settlement.

Water Sensitive Urban Design

Water Sensitive Urban Design is not considered to be as high profile an issue as in some other Australian States. Due to the topography and intensive surrounding infrastructure, there are limited opportunities for WSUD in the major streetscape projects being undertaken by Council.

Infrastructure

Services often require moving or lowering, or the installation of root barriers, even though the root barriers may have a mainly symbolic role. Council is installing new multi-purpose Smartpoles. These require larger footings, to be located in tree root zones. Overhead cable bundling is being undertaken to reduce the impact of pruning. Undergrounding of powerlines is undertaken in major streetscape upgrades such as those in Redfern and Glebe.

Planting and establishment practices

Minimum 100 litre street trees are planted in suburban areas, with a minimum 200 litres in the CBD. The larger container sizes allow for the trees to be clear of pedestrian head heights more quickly, and drastically reduce the rate of casual vandalism (the City has less than 3% of trees vandalised). The preference is not to plant trees in summer. Instead planting occurs mainly in autumn, through to October each year. For larger streetscape projects, there is a preference for planting some time after streetscape works are completed (bituminising the opening in the interim) to allow planting in the most appropriate season. However, this is not always possible due to the need to deliver completed projects. Incorrect establishment practices by contractors continue. For example lack of hand watering of the rootball. Incorrect planting depth has been an issue, which allows trunk sway and damage at the interface between tree trunk and surrounds, due to the large gap left between the root ball and the final pavement levels.

These issues have recently been addressed with the responsibility for tree supply, planting and maintenance being transferred to the tree maintenance team. Maintenance consists of 2-3 visits per week following planting until the second year, when this is reduced to one visit per week, or more if the tree is located in a harsher environment. Trees are maintained at this higher frequency for a minimum period of 24 months, before reverting to the City's annual maintenance cycle.

Implementation

There are few greenfield sites, with most work being on retrofitting. Ashmore Estate incorporating WSUD is one exception. In the CBD, half of the trees have a life span of approximately 20 years in the harsher locations. In some instances a twenty year rotation of trees would be desirable, but the intention is forgotten over time, and is hampered by sensitivity to tree removal and replacement by Councillors and the community.

9.3.5 Sydney reference projects

Earlier projects

Circular Quay/Customs House. A successful early project to partially pedestrianise the CBD frontage at Circular Quay, including the large public space in front of the historic Customs House building . The earlier *Ulmus parvifolia* (Chinese elms) were replaced with *Celtis* species 6 years ago.

Pitt Street Mall. Pitt Street Mall is an example of the creation of pedestrianised malls in the shopping precincts of Australian capital cities. A successful design in which Chinese elms (*Ulmus parvifolia*) were planted in tree vaults with a timber surface over the tree pit, supported on a suspended steel frame. An older project, which was built prior to the use of structural soils.

Martin Place. Considered to be the Sydney CBD's main public space, the streetscape was redeveloped in the lead up to the Sydney 2000 Olympics. 'Permeable' granite pavers with small perforated holes were installed around the tree bases. However these clogged with fines after 12 months and have provided no benefits after the tree has become established.

George Street. Even though relatively narrow in width, George Street is considered the 'main street' of the Sydney CBD. It was substantially upgraded for the 2000 Olympics, including footpath widening and Plane tree (*Platanus orientalis*) planting. Unfortunately some street trees within the avenue have since been removed to provide access to large building sites, and re-establishing trees in the main street of the City is proving to be difficult.

Chifley Square. The design of Chifley Square has set a precedent for palm tree planting in the locality leading down to Circular Quay.

Recent and current projects

Boulevard projects

Three proposals to create tree lined boulevards, lacking in the CBD, were initiated under a previous Council administration. These were all based on carriageway reductions. Oxford Street has been completed, but with a less generous footpath widening than originally intended. The William Street project was facilitated by the development of the cross-city tunnel, conditional on reducing traffic capacity in William Street. The Broadway proposal, involving traffic lane removal and creation of a tree planted median, was not pursued by Council and remains a lost opportunity unlikely to happen now with major redevelopment occurring on both street frontages and a possible light rail in the centre of the street.

Darlinghurst Road, Kings Cross

Description. In the Darlinghurst Road, Kings Cross upgrade, street trees were planted in a new and innovative tree pit design, below a suspended pavement, which included stormwater diversions to the new tree pits in the footpath.

Planting details. Trees were planted in pits below a suspended pavement, with an air cavity below, for horticultural and WSUD purposes. Council invented a suspended tree grate that looked like the standard civil design pavement. A flexible rubber detail was provided around the tree trunk. However the tree base is lower down and the trunk sways more than at the base, resulting in damage to the tree trunk and surrounding infrastructure. It is also not possible to access the air cellar. Council will not pursue this design in other projects as it is too complex. Structural soils were not utilized in the project.

Project issues. Darlinghurst Road in Kings Cross is a very grimy street, and water quality issues have arisen, as runoff to the tree pits is not filtered. The project was intended as a bioretention experiment, but there was no monitoring. The idea was not carried forward to other projects, although it was initially planned for the Oxford Street upgrade. Kings Cross is a difficult site, with high pedestrian volumes and vandalism issues. One proposal was for temporary displays of hanging baskets to add vandal resistant greening to the street.

Oxford Street

Description. The Oxford Street upgrade was a $30 million project including footpath widening, planting Plane trees (*Platanus orientalis*) in the footpath, moving back awnings to accommodate tree growth, installation of Smart poles, and a 2.5-3.0 m wide structural soil trench.

Planting Details. The planting detail comprises granite paving on a suspended slab supported by a steel grate over the tree pit. Terrabond™ is installed in the tree pit opening, with a rubber surround around the tree base (intended to last only 6-12 months). A watering point is included in the design, with supplementary watering of the rootball from above required during establishment. A double stack of interlocking air cells was also installed, wrapped in geofabric.

Project issues

- There have been a number of issues related to design detailing and planting and establishment practices by the landscape contractors. These include tree sway and trunk movement due to the below-pavement planting depth, resulting in destruction of the rubber tree surround.
- Insufficient watering has resulted in trunk damage.
- The SmartPoles® installed also require larger footings, resulting in loss of root space.
- In some ways this was a flawed design. The current Council put back the land gained by traffic lane removal (originally intended to be used for tree space) as widened bus lanes, for use by cyclists also as a shared bus/cycle lane. This has cost a once in a lifetime opportunity of gaining 1 m of footpath on each side of the street.
- It was also not possible to remove the lane near College St/Whitlam Square.

William Street

Description. The William Street upgrade was an RTA project resulting from the Cross City Tunnel, which included an agreement to reduce the traffic capacity of some arterial roads to encourage tunnel use. The project also included some input from Council. This was a major streetscape upgrade involving removal of a traffic lane, footpath upgrade, installation of SmartPoles®, removal of all existing trees and new tree planting of Plane trees (*Platanus orientalis*) in the parking lane. Trees were planted in the parking lane due to limited footpath space and in an effort to prevent any future road widening by the RTA.

Planting detail. A structural soil trench was provided, without the suspended grate detail used in Oxford Street.

Project issues

- This was a project with good intentions, but poor planting and maintenance practices, with some trees planted too deep and sun burnt trees. Three trees have been lost following a hot summer. The project was managed by the builder, hired and managed by the RTA / Cross City Tunnel, without any Council control.
- The structural soil was also not installed properly.
- SmartPoles® with large footings were also an issue.
- Almost all 76 trees had to be replaced due to death or poor establishment, and Council negotiated that its own tree management team would undertake supply, planting and

establishment, to ensure the works were completed properly. Replacement costs were paid for by the RTA.

College Street. One of the latest CBD upgrades, including installation of Plane trees (*Platanus orientalis*) in the footpath. Tree surrounds comprised granite setts in Terrabond™.
Riley Street. An example of overhead cable bundling, with *Eleocarpus reticulatus* (Blueberry Ash) trees planted in the street.
St. Mary's Road. The existing Hoop pines (*Araucaria cunninghamii*) suffering from compaction of the decomposed granite surrounds. This was replaced with Terrabond™ and subsurface drainage to improve tree health.
Kent Street. Planting of poplars (*Populus* spp.) in the narrow, shaded footpath.
Darling Harbour. Planting of Hills Weeping Fig (*Ficus hillii*) and palms by the Sydney Foreshore Authority. The City Council, however, prefers not to plant *Ficus hillii* in CBD streets due to its ultimate large size, structural branch issues and vigorous root growth.
Piermont. Planting of Hills Weeping Fig (*Ficus hillii*) by the Sydney Harbour Foreshore Authority in the redevelopment of Piermont for housing.

Village Main Streets

Council sees itself as a 'city of villages' and is redeveloping the 'main streets' in a number of these local 'villages'.

Redfern Street

Description. Recently completed, Redfern Street is the first 'village' main street. A key consideration was how much space is available, and who to give it to? There were alternative traffic streets running parallel on each side of Redfern Street, so traffic in the main street could be slowed to create a safer environment. But cyclists could not be diverted as Redfern Street is part of a strategic East-West cycle link. The project also provided an opportunity to activate street frontages. Marginal footpath widening was undertaken, with a narrowed carriageway, and footpath blisters. Street trees were planted in either the footpath or parking lane.
Planting detail. *Flindersia australis* (Crows Ash) trees were installed in tree pits with a lowered surface, covered by large standard tree grates. Tree pits in the parking lane were also protected by bluestone wheel-stops. The lowered surface enabled passive irrigation of trees planted in the parking lane. Trees were installed in structural soil, but in generous tree cells rather than continuous root channels. The requirement to retain existing street trees makes it difficult to install continuous trenches. A high pressure gas line was also located under the parking lane.
Glebe Point Road. Glebe Point Road is being upgraded as a village 'spine' with retention of the majority of existing street trees. Overhead power cables were undergrounded, and new Poplar (*Populus* spp.) trees were planted within the footpath area.

Future projects

Cook and Phillip Park. Cook and Phillip Park was previously upgraded as part of the development of the adjacent aquatic centre, but with little consideration for biological tree needs and water use. Trees were removed or damaged and the soil profile changed. Current proposals are for root plate decompaction in parks, involving air knife and mulching. A new underground tank is proposed with provision for pumping to adjacent Hyde Park for irrigation.

Northern CBD

Narrow streets with tall buildings create shading issues in the northern part of the CBD. Generally poorer performing tree species are being replaced with advanced palms. This is a development on the theme created by palm plantings at Chifley Square and Circular Quay. Palms now also follow the alignment of the former tank stream leading down to Circular Quay. In a sense this is a landscape gesture, with the concept of Cabbage palms (*Livistonia australis*) in a sheltered valley, but is also functional in terms of tree survival.

Phillip Street. A highly shaded street in the legal precinct with poorly performing Hackberry (*Celtis* spp.) trees to be replaced with palms.

Bent Street. Existing Plane (*Platanus orientalis*) trees, which were not planted properly, are to be removed and replaced with palms.

Young Street. Palm avenue is being installed in stages.

Pitt Street. Designated for palms, with some intermittent planting being undertaken, with the street considered to be a 'work in progress' over the next 10 years as other trees slowly require replacement.

King Street. King Street is a key CBD east-west cycle link to Pyrmont Bridge/Anzac Bridge. Two way cycle flow is required in a one way street, so Council intends to provide a 1.5 m median with tree planting. This will act as a traffic buffer for the contra-flow cycle lane, and also help to civilize the street and modify street scale. Only 1 m is required for the median, but it will be widened to 1.5 m to accommodate street trees and lighting poles. Council also intends to pursue the idea of a continuous structural soil trench, for the whole block. The *Street Tree Master Plan* nominates Liquidambers (*Liquidamber styracifolia*) for the street, but these create issue with cyclists due to spiky fruit drop, so a sterile form is being sought.

Stanley Street-East Sydney. Stanley Street, Sydney's little Italy, is one of the City's main café hubs. The local community has requested renewal of the area. The project includes the comprehensive upgrade of the Stanley Street hub (between Yurong and Crown Streets) and includes new paving, new street trees, improved and feature lighting, footpath widening and improved accessibility. New street trees are to be installed in the footpath and parking lane, using the *ArborGreen* system of subsurface root cells with, subsurface watering and aeration rings connected to stormwater runoff from downpipes from the adjacent shop fronts. Tree pits in the parking lane are 8900 mm long, 1800 mm wide and contain 3 layers of soil filled root cells supporting the compacted road base and road paving.

9.3.6 Summary

Table 48 provides a summary of the different practices identified in the City of Sydney case study.

Table 48: Sydney Practices Summary

Practice	Reference Project
Streetscape design	
Footpath widening-marginal	George Street, Redfern Street
Footpath widening-half traffic lane removal	Oxford Street, William Street
Planting in parking lane-buildout	William Street
Planting in parking lane-with wheel stop	Redfern Street
Median planting-contra-flow bike lane	King Street
Below ground design	
Containerized-below ground tree vault	Pitt Street Mall
Structural soils-continuous trench	William Street, King Street
Structural soils-cell in parking lane	Redfern Street
Arborgreen root cells-in parking lane	Stanley Street (proposed)
Arborgreen root cells-in verge	Stanley Street (proposed)
Suspended pavement with air cavity	Oxford Street
Tree pit surface	
Suspended timber deck	Pitt Street Mall
Tree grate	Redfern street
Suspended pavement-on metal frame	Darlinghurst Road, Oxford Street
Granite setts in resin bonded gravel	Standard detail. College Street
Resin bonded gravel	St Mary's Road
Rubber joint at tree base	Oxford Street
Water management	
Bioretention tree pit-in footpath,	Darlinghurst Road (trial)
Bioretention swale	Victoria Park
Passive irrigation-tree in road surface (lowered)	Redfern Street
Passive irrigation-subsurface irrigation ring (from adjacent buildings)	Stanley Street (proposed)
Perforated pavers	Martin Place (unsuccessful)
Infrastructure	
Lowered tree pit surface	Oxford Street, Darlinghurst Road
Aerial bundled cable	City wide-Riley Street
Verandah cutbacks	Oxford Street
Tree species selection	
Shade tolerance-narrow streets. Palm spp.	Chifley Square, Northern CBD
Shade tolerance-narrow streets. Poplar (*Populus*) spp.	Kent Street
Source: Case study interviews.	

9.4 City of Brisbane

9.4.1 Introduction

Meeting with Lyndal Plant (Natural Environment and Sustainability Branch) and Scott Chaseling (Urban Designer) 5 June 2007.

9.4.2 Local context

NOTE:
This figure is included on page 213 of the print copy of the thesis held in the University of Adelaide Library.

Figure 27: Central Brisbane

Unlike other capital city Council's, Brisbane City Council administers the whole of the greater Brisbane metropolitan area. It has an area of 1367 sq km and a population of 1,007,901 (2007), making it the most populous local government area (LGA) in Australia.

The Brisbane CBD is located on a bend in the Brisbane River (Figure 27). The central city grid developed from a convict settlement established in 1825. It is bounded on three sides by the mangrove lined river, and to the north east by the suburb of Fortitude Valley. The Brisbane Botanic Garden adjoins the CBD at the bend in the river at Gardens Point.

The original main road of Queen Street has been converted to a pedestrian mall. The mall was opened for the 1982 Commonwealth Games and extended for the 1988 World Expo.

The southern side of the CBD has been separated from the waterfront by a Freeway system. Victoria Bridge links the CBD to the Southbank area, which includes the city's cultural institutions and the Southbank Precinct. The Southbank precinct was the site for the 1988 World Expo and was subsequently converted to the Southbank Parklands. The Southbank Corporation is responsible for the planning of the Southbank precinct. The Brisbane City Council area contains half a million street trees and an unknown number of park trees. Council has data on tree cover by suburb and by private/public ownership. There is estimated to be 45.5% cover in the city area. Brisbane also has a humid subtropical climate, and a requirement for year-round shade.

9.4.3 Street tree management

Strategic level

Brisbane has a strong shading agenda due to its subtropical climate. Year round shading is required for pedestrian comfort, and to support Council's City Shape program. In the City Shape program, Council is trying to get people to live in denser areas, which require the provision of greenery. Council has a mandate for 140,000 new dwellings. Community preference is against development in green areas, so Council is supporting a pattern of development by infill, married to the existing transport infrastructure.

Water is a risk issue rather than a policy driver. Trees are still seen as part of the problem in a drought situation, rather than a solution. There is a need to justify the planting of trees. There is a need for access to recycled water. There is also a need to rethink considerations such as the quality of tree stock and improved specifications for tree establishment and maintenance. There is a challenge to rethink practices to both conserve water and give trees the best chance of survival. There are also a number of 'myths' related to drought and trees, including that drought affected trees fall over.

Urban tree policies

Council has a Street Tree Policy. It also has a *Centres Detail Design Manual*, (Brisbane City 2005) which includes species recommendations for streets in suburban centres and in the CBD. The *Manual* includes specifications for tree trench technology and dedicated tree spaces.

Streetscape policies

CBD Master Plan

The CBD Master Plan has a number of aims, including greening of the CBD.

Subtropical Boulevards Strategy

This is an approved strategy, which aims to create locally relevant subtropical boulevards, as an alternative to the traditional avenue with a tree monoculture, symmetrical design and regimented spacings. Design principles for subtropical boulevards include:

- Lush planting
- Mix of species
- Grouping of trees
- Lush understorey
- Year round flowering and colour

Examples of subtropical boulevards include:

- Grey Street, Southbank
- Coronation Drive
- Melbourne Street, east of Victoria Bridge
- Keith Smith Drive

Signature Projects.

Up to 2004 the Urban Design unit has been undertaking two complementary projects; the Suburban Centres Improvement Projects (SCIPS) and Inner City Capital Works Projects-City Signature Projects.

Suburban Centres Improvement Projects (SCIPS). Capital works projects for suburban shopping centres, aim at breaking the cycle of 'big boxes', arising from Council's Living Villages project. Up to 40 SCIPS projects have been completed, the first one at the Wilson centre.

Inner City Capital Works Projects-City Signature Projects. City Signature Projects are aimed at improving the viability of city businesses, and adding vitality to city streets and lanes. Albert Street was the first such project. Queen Street Mall was a partnership between Council and the Queen Street Mall Business Association.

Projects are delivered through the Urban Design section and City Design documentation. The bulk of SCIPS projects require a 50% majority consultation agreement. City Signature projects, however, are imposed. Under the City of Brisbane City Act 1924 (Queensland 2009) Council can levy traders if project benefits are demonstrated. Adelaide and George Streets were delivered through a levy system, but with reduced consultation. Melbourne Street was a hybrid of City Signature and SCIPS. Property owners voted, but had little say in the outcomes.

Residential streets

Council is also reviewing the possible reconfiguring of residential streets, which are excessively wide, looking at narrowing of road pavements with improved landscape and active transport outcomes. The economic implications are being investigated, and there is a need for political and community support.

Council Surveys

A program of Council surveys has asked questions about the need for green spaces, with people recognising the need for trees.

Scenic South East Queensland.

A regional website project, mapping scenic amenity for Brisbane, uses scenic value ratings. A layering exercise has lead to deep planting policies.

Study of tree planting in infill development.

A consultancy has been undertaken looking at the role of trees in medium to high density development scenarios, which relate to the future shape of development in Brisbane. The question being asked is, 'how can Brisbane's subtropical landscape be integrated into medium-high density typologies?' Experts have looked at these typologies in terms of dwellings per ha of infill development. These studies have highlighted the need for a dedicated spatial allocation for medium-large shade trees, Brisbane's iconic subtropical landscape elements. This needs to be done in-ground, not in containerised planters. The study showed how to reconfigure underground car parks, a key factor restricting tree planting. The study recommended dedicating 10% of the site to deep planting. The planning requirement is already for 20% open space, and part of that should have a certain quality allowing large shade trees. The development industry supports this in principle, but does not want a prescriptive approach.

Organisational structure

Council's organisational structure includes the following levels:

- The broader agenda, including Council's vision, Corporate Plan and Lord Mayor's policies.
- City Planning, and Natural Environment and Sustainability are the two main policy drivers, (as well as Transportation and Traffic, and City Assets).
- The Urban Design section plays a conceptual role and oversees projects. It acts as a purchaser to City Design. Local Asset Services is responsible for on ground delivery.
- City Design provides project documentation.

Design standards

Standard planting details are contained in Council's *Centre's Design Manual* (Brisbane City 2005). The *Centre's Manual* includes specifications for tree trench technology and dedicated tree spaces.

9.4.4 Current practices and issues

The following is a summary of the main street tree issues raised, and the related practices being adopted by Council.

Tree planting approach

The general approach to street tree planning should be to:

- First, justify the need for trees in new development and urban renewal. An holistic approach based on livability.
- Second, create space for the tree, based on arboricultural principles. Spatial allocation is a critical factor, with definition of minimum space requirements.
- Third, make the tree work in that space. Provide the right qualities in the space, to optimise the benefits.

Preferred Tree Species

Brisbane has a history of subtropical tree species plantings, which make flowering in every month possible. Harry Oakman was responsible for the early subtropical plantings in Brisbane. Leopard trees (*Caesalpinia ferrea*) from Brazil have been the favoured CBD tree in the past. They have few surface root issues and tolerate poor aeration. Council is not overly concerned with native/non-native issues. The character of Brisbane is a mix of native/non-native species.

Recent plantings include Weeping Lillypilly (*Waterhousia floribunda*) in George Street, Crows Ash (*Flindersia australis*) in Albert Street and Tulipwood *(Harpullia pendula)* in Elizabeth Street. The top five tree species are *Waterhousia floribunda* (Weeping Lillypilly), *Buckinghamia celsissima,* (Ivory curl flower), *Cupaniopsis anacardioides (*Tuckeroo), *Syzygium leuhmanii* (Small leaved Lillpilly), and *Tabebuia rosea* (Pink trumpet tree). Kauri pines (*Agathis robusta*) are a local signature tree. Melia trees (*Melia azeradach*) are subject to a local caterpillar pest. Palms are not highly regarded in streetscape design as they have no shading value.

Below ground design

Council has progressed from root channels with structural soil (first generation projects) to suspended slab construction (second generation projects). The ideal depth is 1.0-1.5 m maximum as deeper there is not proper aeration for root growth.

Brisbane uses large spalls in its structural soils, while US and Amsterdam soils use smaller gravel. Large rocks still give 40% void and 60% solid, but the size of the voids between the larger spalls are greater and better suited to subtropical trees. The size of the voids could be graduated away from the rootball, but that would be complex. Trenches are backfilled with structural soil, the drainage layer first, then the larger stone layer, then backfilled with soil (allowing 40% soil volume to fill the voids). Stones must touch or they will compact. The soil layer is washed in, and then the drainage system is tested. As there is an equal volume of stones to soil there is a reduced growing space.

In terms of suspended slabs, Council now prefers to use suspended slabs which provide 100% growing medium. Pavement openings can be provided for inspection. Testing can be done with steel rods inserted into the soil, with corrosion an indicator of soil aeration. Soils are installed in two layers, with different tolerance to shrinkage. The B horizon has little organic matter so less shrinkage. The A horizon in the top 30 cm has more organic matter so is better aerated, and can be topped up with shrinkage. Under suspended slabs shrinkage in the top layer is beneficial as it creates aeration of the trench between tree pits. *AS4449* (Standards Australia 2003) sets ranges for soils, but needs more detail.

Soil volumes are a major issue, involving an arboriculture/design interface. The required volume will depend on maintenance inputs, and a tree can be grown in a small container with water and nutrient inputs. A larger, better quality space will require less inputs. Better information is required on soil volumes. Reference is made to Ross Clark (Clark 2003) and NATSPEC root volumes.

Tree pit surface

Brisbane City Council signature tree grates are used throughout the CBD. These are powder coated aluminium 1200 mm x 1600 mm as at Brisbane Square or 1600 mm x 1600 mm as at City Hall. They have radial slots and the central opening can be enlarged with an angle grinder. Tree grates are an issue in pedestrian areas, as opposed to edge of kerb locations, due to slip and trip hazards if located in the direct path of movement.

Infrastructure

Some projects involve costly service relocations, which cannot be avoided on key projects. In the past, powerlines have been undergrounded. Due to costs, cables are now put in for future undergrounding. Removing powerlines increases design scope. Energex cables sit 0-300 mm off property boundaries, with water, gas and Telstra usually further out. Council does an underground survey first, including potholes. Fibre optics are a nightmare and too costly to relocate.

Water management

Trees in above ground podia are dying due to drought. There are a number of examples of podia planting, as car parks and bus stations are located below some CBD streets.

Implementation

Council has a good understanding of the need for trees, including in the CBD, based on community surveys. The community, developers and politicians see the need. The key is making it happen, as the required knowledge is available. The fundamental issue is contested space. A site by site approach is required.

There are economic limits on streetscape improvements. Council's subtropical boulevards are only approved if they are not seen as new capital works projects. An opportunistic model is best, for example waiting until a big transportation project occurs on a major road. Council will fund CBD demonstration projects. Tree planting can also be attached to water, shade, public transport, active transport (cyclists) and economically driven projects. Transportation is a good partner and public/private partnerships are also possible, for example Roma Street in the future.

9.4.5 Brisbane reference projects

History of root channel installations

Ten years ago saw the first use of structural soils in Albert Street. George Street is a second generation project with a suspended slab detail. There has been a difference in funding sources for first and second generation projects. Melbourne Street is a contemporary design. The Roma Street boulevard will be the next generation of root channel applications.

Earlier projects

Queen Street Mall. Queen Street Mall was developed as a partnership between Council and the Queen Street Mall Business Association. The Mall was revamped 6 years ago. Trees are containerised as car parking stations are located below the street. In designing containers, Council undertook soil volume calculations, and then reduced them to minimal requirements. Understorey plants in containers are recycled, which root prune the trees at the same time, renewing the space for new tree root growth and helping prevent water-logging.

Adelaide Street. An early upgrade of the road and footpath including paving, roadworks and planting of Leopard trees (*Caesalpina ferrea*).

Albert Street. Albert Street provides an important link between the CBD and the Botanic Garden. The project began 12 years ago when the Lord Mayor wanted the street improved and pedestrianised to the Botanic Gardens. Crows Ash trees (*Flindersia australis*) were finally selected due to their upright, elliptical shape.

Footpaths were widened by removing a parking lane on both sides. Planting space was limited; however, as a new trench was required for new kerb and stormwater, it was decided to also introduce a root trench. Calculations were done for soil volumes for mature Crows Ash (*Flindersia australis*) trees, using the Bassuck method relating water needs to soil volume. Each tree required 8 m^3 of soil volume so a structural soil approach was adopted. The vision would not have been achievable with a standard 1.0-1.2 m^3. Crows Ash trees (*Flindersia australis*) were planted in a root trench filled with structural soil, providing 5-6 m^3 of soil volume for each tree. A layer of understorey plants was also provided, which assists in the active management of the space.

This was in some ways a ‘too successful’ project, which has attracted many outdoor eating venues and coffee shops, with many fixed and temporary balustrades and umbrellas, some conflicting with tree canopies. The trees are doing well though.

GPO frontage in Queen Street. Tulipwood (*Harpullia pendula*) are planted in the granite paved footpath outside the GPO. Council usually uses more economical Boral pavestone, but used granite for this important public space. A granite slab tree grate with 13mm perforations was installed on a metal sub-frame over each tree pit. These, however, have been found to create a footpath hazard due to the size of the holes and the metal security collar around the tree base.

Recent projects

Melbourne Street. Melbourne Street was upgraded in 2002/03 as a contemporary design project, and was the first real subtropical boulevard in Brisbane. The project had 50/50 funding for 10 years with a levy upon property owners. Melbourne Street links the CBD to the West End, a ’grungy’ suburb with a large number of students within a large walking catchment. Existing footpath conditions were poor, so the project aimed to emphasize pedestrian amenity, with seating, rest stops, fountains and a shaded journey. Existing street tree plantings comprised a Leopard Tree (*Caesalpinia ferrea*) monoculture, with existing trees located in the services zone. The design charter was for a subtropical boulevard including:

- A mix of species, creating a mixed canopy with some taller Kauri pines *(Agathis robusta)* poking through, reflecting the natural habitat.
- Tree species included *Waterhousia floribunda* (Weeping Lilypilly), *Harpullia pendula* (Tulipwood), *Agathis robusta* (Kauri pine), *Flindersia brayleyana* (Queensland maple), as well as *Syzygium leuhmanii* (Small Leaved Lilypilly) and *Livingstonia nitida* (Cabbage tree palm).
- A lush understorey including *Philodendron* spp. and *Liriope* spp. punctuated with flashes of colour from plants such as *Croton* spp.
- Grouped versus traditional avenue planting.

The existing street trees comprised small sized stock sitting over services. New plantings comprised large stock, for instant effect, and overplanting of the understorey. Past Merrivale Street the large area devoted to on-street car parking was rationalised, giving an extra half lane to each side of the road as footpath, and moving the proposed trees out of the existing services zone. On the other side of Merrivale Street there is a 110 high voltage secondary feed to Brisbane city, and Energex imposed restrictions on tree planting, as the cable sits on a sand base and could be subject to damage. Some trees were planted in odd locations, and some precast concrete seats were fork lifted in, to allow future cable access. The design also included a continuous root trench on both sides, with a suspended slab detail.

In one block of the street, stormwater runoff was directed to the root trench, with some percolating down to an underground storage tank for harvesting and irrigation. Other runoff is filtered and provides passive irrigation of the trees, without a pumping system. The system has had some problems including pumps silting up. The system includes purpose designed kerb inlets which also provide initial filtering of stormwater runoff.

Outside the Commonwealth Bank at Boundary Road, the previous roundabout had been removed, so the footpath was built out to create a small urban square, which included lush plantings and landmark ‘subtropical’ artworks, a shade structure and seating. Due to the planting layout, the street needs a higher level of maintenance.

Grey Street. Grey Street was redeveloped by the Southbank Corporation, on public land, but funded by the developers. The project aims to create a new prestige retail street at the rear of the Southbank precinct. Planting comprises Kauri pines *(Agathis robusta)* in the median and Tuckeroo (*Cupaniopsis anacardioides*) in both footpaths, as well as a vine trellis shade structure on both sides of the street. The tree pit design involved part suspended slab construction.

Brisbane Square. Informal planting of *Waterhousia floribunda* (Weeping Lilypilly) trees in the major public space created outside the new Brisbane City Council landmark building. The use of tree grates in a public space is seen as an issue due to conflicts with pedestrian desire lines.

George Street. Suspended slab construction with planting of *Waterhousia floribunda* (Weeping Lilypilly) street trees. The street acts as a wind tunnel impacting on the street trees.

Roma Street Parklands boulevard. The boulevard adjacent to the Roma Street parklands includes a structural soil trench below street trees planted in the car parking lane.

Future projects

Roma Street. Roma Street is to be developed as the next generation subtropical boulevard. Road capacity is being tested with traffic modeling to give the proposal credibility. The vision is being worked up in parallel with the traffic study.

Grey Street. The existing boulevard to be extended further west by Council, with shared funding.

Woolloongabba. An inner urban scheme with proposals for swales, stormwater retention below ground and details for a high density urban environment with busy roads. The planting of three rows of street trees is proposed, comprising:

- Signature trees in the parking lane in buildouts.
- Trees on the kerb line fed with stormwater, using a standardised kerb inlet. Trees are set in a grate or with underplantings, at 6 m spacings.

- Secondary trees at the property boundary, in wider streets. Possibly with permeable paving.

9.4.6 Summary

Table 49 provides a summary of the different practices identified in the City of Brisbane case study.

Table 49: Brisbane Practices Summary

Practice	Reference project
Streetscape design	
Alternative to traditional avenue (subtropical boulevard)	Melbourne Street, Albert Street, Grey Street, Roma Street (proposed)
Informal, grouped planting	Melbourne Street
Mixed species	Melbourne Street
Footpath widening-one traffic lane removal	Melbourne Street
Footpath widening- traffic lane removal both sides	Albert Street
Median planting (different species to verge)	Grey Street
Opportunistic group planting	Melbourne Street square
Shade structures	Grey Street, Southbank
Three rows of trees (parking lane, verge, property boundary)	Wooloongabba (proposed)
Below ground design	
Structural soils-continuous trench in footpath	Albert Street
Structural soils-continuous trench in parking lane	Roma Street Park boulevard
Suspended slab-continuous trench in footpath	Melbourne Street, George Street
Containerized-above ground with understorey	Queen Street Mall
Tree pit surface	
Signature tree grate-suspended	Standard detail
Granite grate with perforations-suspended	Queen Street GPO
Underplanting	Melbourne Street
Underplanting (removable planters)	Queen Street Mall
Water management	
Passive irrigation-tree in verge	Melbourne Street, Wooloongabba (proposed)
Modified kerb inlet	Melbourne Street
Underground storage and reuse	Melbourne Street
Permeable paving in footpath	Wooloongabba (proposed)
Infrastructure	
Undergrounding power	Major projects
Cable installation for future undergrounding power	Policy
Service relocation	Major projects
Precast removable furniture over services	Melbourne Street
Tree species selection	
Mixed tree species	Melbourne Street
Source: Case study interviews.	

9.5 City of Perth

9.5.1 Introduction

Meetings with Barbara Shipway (Senior Urban Designer) and David Hammer (Arboriculturist) 13 October 2008.

9.5.2 Local context

NOTE:
This figure is included on page 223 of the print copy of the thesis held in the University of Adelaide Library.

Figure 28: Central Perth

The City of Perth is located on a bend in the Swan River. The City has an area of 8.75 sq km, with a resident population of approximately 13,500 in 2007, with a daily influx of approximately 120,000 workers and visitors. The City of Perth was much more extensive in 1995, but has been split up into several towns: Victoria Park, Cambridge, Vincent and Perth itself. The City can be divided into four main precincts: Perth CBD, Northbridge, East Perth and West Perth.

The urban form of the Perth CBD (Figure 28) comprises a grid of four long east-west streets running parallel to the river (St. Georges Terrace/Adelaide Road, Murray Street, Hay Street and Wellington Street) and a number of shorter cross streets leading down to the waterfront (much of which is reclaimed land). Sections of Hay Street and Murray Street, between Barrack Street and William Street, have been converted to pedestrian malls. Forrest Place adjacent to the Post Office has also been configured as a major pedestrian space. The CBD is defined to the north by the railway line and to the east by Kings Park. Other precincts include the Northbridge entertainment precinct, on the northern side of the railway line, and the mainly residential precincts of East and West Perth. Large parts of the City are under the control of State government authorities, including areas of the freeway through the city. The East Perth Redevelopment Authority is responsible for the areas of: East Perth power station, Claisebrook Cove, Riverside, New Northbridge, Perth Cultural Centre, and The Link. Kings Park also is not part of Council and is administered by its own board. Perth and its region are characterized by sandy soils with low water holding capacity. The region is also characterized by a hot climate with little rainfall in summer, with most rainfall occurring in large events. Perth is also characterized by strong SW afternoon winds known as ‘The Fremantle Doctor’.

In the adjacent Subiaco council area, Subiaco central was developed by the Subiaco Redevelopment Authority, a body similar to the current East Perth Redevelopment Authority. Subiaco central was developed around a lowered Subiaco railway station as a railway station centred Transit Oriented Development (TOD), part of the State governments wider network city planning policy.

9.5.3 Street tree management

Strategic level

Perth is a hot city so trees are important. Council attempts to put them in everywhere possible, and they are seen as fundamental, a ‘given’, to the city. Council currently has a mayor and elected members open to new ideas and change. A large number of things are happening now, including the approval of a new *Street Tree Framework* (City of Perth 2008). Council has recently shown a high level of trust in its officers.

The north-south streets in the city centre are currently one-way, but are being changed to two-way, with the objective of slowing traffic speeds in the city centre. Many of these streets have not had trees, which will be included in the new two way designs, however there may be less tree planting opportunities now at road junctions.

Urban tree policies

Council has recently adopted a *Street Tree Framework* (City of Perth 2008).This is based on the Perth *Public Places Enhancement Strategy* (City of Perth 1997) and is structured around a hierarchy of streets, including main streets, boulevards and residential streets, and the ‘feel’ Council wishes to give them.

Perth is a capital city, so the main priority is for shade and comfort. In the main streets, large trees are preferred, with smaller trees in the narrower streets. There are issues with native species as street trees, however natives are preferred as the appropriate species for the waterfront and Kings Park. Special trees are also nominated for nodes and for ceremonial streets such as Parliament Place. The Street Tree Framework has 4 components

- **Tree Selection Criteria**. Based on the *Public Places Enhancement Strategy*. (City of Perth 1997). It includes objectives and design principles and matches tree species with the street hierarchy of the City, Including City streets, special indigenous zones, and special areas such as Riverside Drive and Parliament Place. It is graphically illustrated in a *Greening Plan*.
- **Tree Species List.** Includes existing species, replacement species and new species to be used in the city. As a guide for replacement, it allows Council to have trees contract grown, and also allows other parts of Council to have an awareness of direction with maintenance.
- **Street Tree Matrix**. A guide for future planting which matches tree species with the street hierarchy. For each street it specifies existing species and recommended species for replacement, identifying any changes.
- **Tree Replacement Guidelines**. Technical notes for tree planting and selection of nursery stock, written by Council's arborist.

The Strategy has been adopted by Council, giving it more strategic value.

Streetscape policies

The *Public Places Enhancement Strategy 1997* (City of Perth 1997) currently under review, provides an integrated framework for future development of the city's public domain. The principles underlying the strategy are to enhance Perth as a vibrant, dynamic and people orientated city. This is to be achieved through a coordinated approach to physical improvements, and by strengthening the legibility and quality of the public domain, including city boulevards, entry points, city avenues, river promenade, squares and parks, landmarks, links to the river, local centres and the civic domain as a focal point.

Council has an ongoing program of gradually transforming one way streets to two way traffic flow in the central city, to make the capital city environment SAFER (Slower vehicles; Accessible grid-more route choices; Friendly to pedestrians; Easier to find your way around; Restricting fast moving through traffic).

Council is redeveloping its existing pedestrian malls to meet the changing commercial needs of the capital city, in accordance with its *Malls Action Plan* (City of Perth 2002a). The related *Malls Draft*

Concept Plan (City of Perth 2002b) illustrates a range of physical improvements to guide enhancement of the mall's public spaces. This includes high quality granite paving and the incorporation of shady resting places or 'outdoor rooms'. The improvements reflect the status of the malls as the State's premier retail areas and key public gathering spaces.

Council is also undertaking a number of streetscape redevelopments. William Street previously had no trees and Council has looked at it strategically. In addition Council is also undertaking studies to beautify and regenerate the West Perth precinct, including a review of the 1993 *West Perth Urban Design Study* (City of Perth 1993).

Organisational structure

Council is divided into a number of sections.

Planning and Development directorate. Urban Development and Strategic Planning are within the Planning and Development directorate.

Urban Development Section. The Urban Development Unit is relatively large even though Perth City Council is relatively small in size. Its aim is to be responsible for the physical improvements of the existing public domain and the creation of new public spaces and facilities throughout the City. Its function is to both design and build projects. Its 23 staff includes 6-7 urban designers with backgrounds in landscape architecture and architecture, 1 Arboriculturist , 4 engineers together with 4 Drafting persons and outside part time consultants. Staff generally work in teams, with design teams lead by an Urban Designer/Landscape Architect. Some smaller projects are project managed by individuals engaging outside contractors, and building teams lead by an engineer. In some cases Council goes out to external consultants for design and construction documentation. The Urban Development Unit designs a variety of areas, from new or altered streetscapes, to changes to parks and reserves, but the focus is mainly on built form, as there is not much open space in Perth, being a capital city.

Strategic Planning Section. The Strategic Planning Team has a strategic focus, to provide direction and vision for the organisation. It includes a climate change officer (Cities for Climate Change project) and environment officer. Ideally it could be part of Urban Development, where ideas could be better passed through, but it tends to operate separately.

Business Units directorate. Within the Business Units directorate are Parks and Landscape Services and Works and Services.

Operations Unit. The Operations Section builds projects and installs trees.

Parks and Landscape Services. Parks and Landscape Services are similar to the old Parks and Gardens sections in councils, providing a landscape maintenance function. Urban Development provides handover reports on project completion. However there could be better links between the two. For example, a project intended as water wise design may later have ornamental annuals planted.

Design standards

Council has design and construction notes which include standard details for tree pits and Council's signature tree grates. This includes a standard 1200 mm x 1200 mm grate and larger 2000 mm x 2000 mm grate for palm trees. Signature grates are of tubular steel tubes, with a non-slip finish, on a steel angle frame. The standard tree pit is 1200 mm x 1200 mm x 1200 mm. Tree pits and grates are set back 412 mm from back of kerb, one 400 mm wide paver and joint, giving a tree setback of approximately 1200 mm including kerb. Council requires that any large item to be set back a minimum 600 mm from the kerb. The setback of the tree pit edge from the roadway also addresses the potential plane of failure issue in relation to the kerb. Council specifies a standard 400 mm x 400 mm x 60 mm exposed aggregate paver in the CBD replacing the previous 500 mm x 500 mm concrete paver, laid on a compacted limestone base. Each site is specific, so in a sense the standards can be considered to be academic. Ideally the standards should also specify greater soil volumes for trees.

9.5.4 Current practices and issues

The following is a summary of the main street tree issues raised, and the related practices being adopted by Council.

Preferred tree species

Signature tree species in the Perth region include a number of Eucalypts: Jarrah (*E. marginata*), Tuart (E. *gomphocephala*), Red Flowering Gum (*E. ficifolia*) and River Red Gum (*E. camaldulensis*). Willow Myrtle (*Agonis flexuosa*) is also a local signature species with a number of large mature trees planted in streets.

A number of Melaleuca (*Melaleuca* spp.) have been planted over the years, with the Broad Leaved Paperbark (*Melaleuca quinquenervia*) one of the better performers, being fast growing and hardy. Queensland Brush Box (*Lophostomen conferta*) were planted in Adelaide Terrace and St George Terrace (the main street in the city). These have had issues with nut drop. They have been in a long time (40-50 years) and Council plans to replace them with another species when removed. Spotted gums (*Corymbia maculata*) were planted in the early 1980's, including in Adelaide Terrace, but have shown variable shape and form due to a variable seed source. Hill's Weeping Fig (*Ficus hillii*) were also planted in the past, but are now being removed due to root issues, but otherwise they have been a good tree.

Council has planted a large number of Phoenix palms (*Phoenix canariensis*), as entry statements at intersections. Phoenix (*Phoenix canariensis*), and Washingtonia (*Wahingtonia robusta*) palms are planted along Riverside Drive as an entry statement to the City. The Riverside Drive palms are 9-10 years old and none have been lost. Council has planted 200 palms over the years, and has only lost 2 or 3.

There are a number of examples of mature Plane trees (*Platanus spp.*) in City parks. Victoria Avenue is the best example, with 80 years old Plane trees creating a very cool and leafy street. Council now tends to plant a lot of London Planes (*Platanus x acerfolia*). A street tree suitability matrix was developed and London Planes (*Platanus x acerfolia*) came out the preferred species, including their 'water wise' attributes.

Illawarra Flame Trees (*Brachychiton acerfolius*) have been planted in Hay Street and Barrak Street. Their popularity was due to a single specimen in the University of Western Australia grounds that flowered spectacularly. However being a subtropical Queensland tree requiring a lot of water, they are not appropriate in Perth. They also fail to provide shade when needed, and have not been consistent in form. Council does not water after three years, so is trying to select trees that do not require it. Point Fraser, on the foreshore, has recently been redeveloped as a native species open space and wetland.

Streetscape design

When Council redevelops a streetscape they try to widen footpaths as much as possible, often achieving a 2-3 m wide footpath pavement. The average street is about 20 m from building line to building line. Because it is a city centre, Perth does not have many narrow streets, as found in suburban areas. Two small streets off Adelaide Terrace (Howard Street and Sherwood Court) were planted with street trees at the insistence of the previous Council, and against the recommendations of Council officers. Trees were planted 400 mm from the kerb (rather than the required 600mm) in a 1.2 m-1.5 m footpath. The trees also sit over services and are in small containers that will have to be lifted every few years.

Building lines are changing in the City, for example new apartment buildings on Adelaide Terrace, which impacts on existing trees and provides an excuse for tree removal by developers.

Below ground design

A priority is providing large volumes of growing medium. However the standard tree pit is 1200 mm x 1200 mm, and the maximum is a 1500 mm x 1500 mm, and outside of that is considered by Council's arborist to be 'pot luck'. There is interest in new systems of underground root cells, such as Deep Root™, and Council intends to experiment. There would, however, be constraints with underground services if cells are to be retrofitted in established areas, which may be more appropriate to vacant sites. There are many underground services in the city, including dead services. Another alternative is linear trenches to achieve better soil volumes, but these are considered problematic due to underground services which include cross services at right angles to the kerb.

Tree pit surface

Council has design and construction notes which include standard details for tree pits and Council's signature tree grates. This includes the standard 1200 mm x 1200 mm grate and the larger 2000 mm x 2000 mm grate for palm trees.

Infrastructure

Council specifies a standard 400 mm x 400 mm x 60 mm exposed aggregate paver in the CBD replacing the previous 500 mm x 500 mm concrete paver, laid on a compacted limestone base.

Water

Perth's rainfall pattern is one of a lot of rain in winter, and then nothing much for 6-7 months. Water restrictions in Perth are not as severe as in most other states, with sprinkling permitted on two days a week. This is due to the availability of bore water, and Council has established a bore water storage lake on the foreshore known as Lake Vasto. The long term viability of bore water due the drying of aquifers is an issue however. The previous Council wanted a lot of greenery, however Council now has a scale of watering for grassed areas which staff works to. Priorities are given to key areas such as Stirling Gardens. With less water Council will look at the use of wetting agents and water-saving crystals.

Water Sensitive Urban Design

Council has not done many WSUD applications due to the cost of retrofitting. A passive watering system is being trailed on one or two trees in Northbridge. The value of such systems in Perth is questioned due to the pattern of limited rainfall and isolated, high volume rain events.

Implementation

The State Government has tended to take over areas of old industry, such as the old Subiaco railway sidings and the East Perth redevelopment area. These areas are handed back to Council when redeveloped. The planning of these areas is supposed to be based on a co-operative approach, which does not appear to occur in reality. If these areas are to be handed over to, and managed by Council, then Council needs to have a say in materials and other items to fit in with their palette. The same applies to tree planting in East Perth, which was not discussed with Council. Western Australia does not have tree protection legislation as found in other states

9.5.5 Perth reference projects

City Malls

Perth has established pedestrian malls in the CBD, in a section of Murray Street, Hay Street and Forrest Place. In some instances there is car parking under, creating conditions similar to the building a roof garden. The City's malls are being redeveloped in accordance with Council's *Malls Action Plan* (City of Perth 2002a) and *Malls Draft Concept Plan* (City of Perth 2002b). Murray Street and Hay Street Malls have been redeveloped, including new in-ground tree pits, however originally the trees were planted in concrete rings.

Murray Street Mall. In the Murray Street Mall redevelopment, Plane trees (*Platanus x acerfolia*) have been planted, with under plantings of native grasses for aesthetic purposes.

Hay Street Mall. Hay Street Mall is narrower space than Murray Street. Plane trees (*Platanus x acerfolia*) have been planted in specially designed tree pits to provide growing space and reduce hardscape conflicts by lowering the tree below the level of the adjacent paving slab. Trees are planted in 1700 mm x 1700 mm x 1470 mm deep (below pavement level) tree pits. Granite paving is suspended over the tree pit on a 1960 mm x 1960 mm steel frame, with a 700 mm x 700 mm trunk opening. Each tree pit opening is surrounded by signature planter boxes, in which flower pots can be changed for year round colour.

Forrest Place. Forrest Place is a large public space strategically located between Murray Street Mall, the GPO and the central railway station, with a car parking station below. Plane trees (*Platanus x acerfolia*) were planted in two configurations. Some were planted in 2 m diameter concrete sleeves going right down to the ground below the car parking level, a challenging environment for tree growth. Council has monitored the soil moisture contents at different levels. In the other, Plane trees (*Platanus x acerfolia*) were planted in a raised 1.2 m deep soil bed, as there is only 1m clearance between the top of the paving slab and the roof of the car park below. The trees have been in for 20 years and are about to be removed as Forrest Place is redeveloped. There is considered to be a case for planting in these difficult situations; however it is necessary to recognise that in 15-20 years the trees will have to be removed and replaced.

Howard Street and Sherwood Court. Street trees planted in undersized tree pits in two narrow streets off Adelaide Terrace.

Barrack Street. Barrack Street is an important street leading down to Barrack Square on the waterfront, which has been planted with Illawarra Flame (*Brachychiton acerfolius*) trees.

William Street. William Street provides a north-south link between future waterfront development, the city centre and Northbridge. The recently completed William Street enhancement, between Wellington and the Esplanade, involved conversion from one-way to two-way flow, reduction of road space and increased footpath space for pedestrians, and physical streetscape improvements including avenue tree planting.

William Street Northbridge (proposed). It is proposed to continue the William Street enhancements into Northbridge, between Roe and Newcastle Streets. This will include removing two traffic lanes and widening footpaths both sides, and new street furniture, lighting and street trees in accordance with the City's design standards.

Northbridge Piazza. As part of ongoing enhancements to the Northbridge entertainment precinct, the old Pallas hotel site, at the corner of Lake Street and James Street, is being developed as a public piazza. The design includes outdoor paved and grassed spaces and a permanent LED screen. The project includes paving of the piazza and the adjacent streets, which are integrated into the public space, with Kimberley stone laid on a concrete slab, to create a unique identity within the city. Dealing with underground services has been an issue in the project. Mature palms are being transplanted and installed in 2 m x 2 m palm grates. Mature olive (*Olea europaea*) trees are also being transplanted from Langley Park on the Perth foreshore, for instant impact. A passive irrigation system has been installed in several tree pits, with a lowered tree pit surface, tree grate and kerb inlet.

Alexander Library. The Plane (*Platanus x acerfolia*) tree lined public space outside the Alexander (State) Library has been redeveloped, with paving re-laid on 3-5 mm screened basalt aggregate to prevent pavement lifting.

9.5.6 Summary

Table 50 provides a summary of the different practices identified in the City of Perth case study.

Table 50: Perth Practices Summary

Practice	Reference project
Streetscape design	
Footpath widening	Streetscape policy
Footpath widening- traffic lane removal both sides	CBD, William Street
Tree trunk setback 1200mm from kerb	Standard detail
Below ground design	
Enlarged tree pit with suspended paving	Hay Street Mall
Tree pit setback 412mm from kerb	Standard detail
Containerized trees over services	Howard Street and Sherwood Court (limited life)
Raised planter bed-over services	Forrest Place
Structural soil cells	Possible future projects
Tree pit surface	
Signature tree grate-suspended	Standard detail
Underplanting	Murray Street Mall
Moveable planter boxes surrounding tree pit	Hay Street Mall
Water management	
Passive irrigation with kerb inlet	Northbridge Piazza
Water saving crystals	To be investigated
Elimination of turf verges	Policy
Bore water irrigation	Lake Vast bore water storage
Infrastructure	
Tree pit lowered below hardscape	Hay Street Mall
Tree trunk and tree pit setback from kerb	Standard detail
Unit pavers on aggregate base to discourage surface roots	Alexander Library
Tree species selection	
Mature tree transplanting	Northbridge Piazza
Gateways and entries - Palm species.	Riverside Drive
Source: Case study interviews.	

9.6 Comparison between cities

The following section provides a comparison between each city on terms of street tree management, and key practice issues.

Local context

As summarized in Table 51 each city varies in terms of local context, including: climate and soils; urban form and street widths; and street tree heritage and tree stock. A key climatic concern is the length of rain-free periods, with Perth experiencing long hot dry spells in summer, with rainfall occurring in large infrequent events. Perth also has sandy soils with low water holding capacity, and strong afternoon sea breezes. In subtropical Brisbane year-round shading is an issue. In Melbourne a key concern is the water quality of the Yarra River and Port Phillip Bay. Urban form influences the space available for tree planting; Melbourne has a formal grid with wide streets, while Sydney has a legacy of narrow winding streets with limited planting space. A combination of tall buildings and narrow streets also creates a difficult shaded environment for trees. Cities may also be constrained by their existing tree stock and historical tree selection decisions. Melbourne has a nineteenth century heritage of streets, boulevards and parks planted with European tree species, which influences current planting choices.

Table 51: Comparison between cities: local context

Topic	City			
	Melbourne	**Sydney**	**Brisbane**	**Perth**
Climate	Temperate. Warm summer. No dry season.	Temperate. Hot summer. No dry season.	Humid subtropical. Year round shade needed.	Temperate. Distinct hot summer with long dry spells rainfall in large events in winter.
Other physical	Water quality Yarra River and Port Phillip Bay	Shading- tall buildings and narrow streets		Sandy soils. Strong SW afternoon winds.
Urban form	Formal 'Hoddle' grid with wide streets and narrower Little streets. Laneway network. Formal boulevards.	Unplanned grid of narrow, winding streets. Lack of boulevards.	Grid on bend in Brisbane River. Riverfront freeway system.	E-W grid with shorter cross streets, on bend in Swan River.
Open space	Formal parks, gardens around grid. Yarra River. More recent Federation Square, Birrarung Marr and Melbourne Square.	CBD bounded by Sydney Harbour foreshore and open spaces-Domain, Hyde Park.	Brisbane Botanic Gardens and more recent Roma Street Parklands. Freeways separate CBD from river. New linear open space in Southbank.	Swan River foreshore and Kings Park.
Street tree heritage	'Garden City' heritage of European Planes (*Platanus orientalis*) and elms (*Ulmus* spp.) in streets, parks, boulevards.	Fig trees (*Ficus* spp.) in large parks.	Mixed palette of evergreen subtropical species, native and exotic, with year round shade and colour.	Mix of exotic and local species (e.g. *Agonis flexuosa*) tolerant of climate and sandy soils. Old Plane trees (*Platanus* spp.)
Pedestrianised streets/spaces	Bourke Street. Mall Swanston Walk (semi-pedestrianised).	Martin Place. Pitt Street Mall. Circular Quay.	Queen Street Mall.	Hay Street Mall. Murray Street Mall. Forrest Place.
Recent urban developments	Southbank. Docklands.	Foreshore-Darling Harbour, Pyrmont.	Southbank precinct.	East Perth.

Strategic policy drivers

Despite local differences, each city has a common agenda in terms of: creating urban amenity in the Australian climate; and a high quality and inviting public realm (Table 52). Each city sees trees as part of the image of its State's civic, retail and tourism focus. The public realm of each city must also meet the needs of both residents and daily visitors (workers, shoppers and tourists). Street tree planting in capital city CBD's is therefore 'mandatory', despite the many constraints on tree planting. These include narrow footpaths, high pedestrian volumes, overshadowing by tall buildings, extensive paved surfaces (often on a concrete slab base), extensive underground services established over the preceding century, and more recent drought and water restrictions.

Table 52: Comparison between cities: strategic policy drivers

Topic	City			
	Melbourne	**Sydney**	**Brisbane**	**Perth**
Urban amenity	Trees part of pedestrian friendly city centre.	Fundamental to city projects-civic amenity. Upgrading public domain in Australia's largest CBD.	Creating liveability. Year round shading agenda in subtropical climate (pedestrian shade-ways). Trees and greenery to create liveability in urban densification (City Shape Program).	Fundamental in a hot dry city (a given).
Other	Ageing (European) tree stock-replacement and succession planning. Lack of species diversity. 'Garden City' image, park and boulevard trees.	Narrow streets with limited planting space. Shading issues-narrow streets, tall buildings. Building on past 1998, 2000 initiatives. Improving on poor past selection and planting and establishment practices. Reinforcing historic themes.	Suburban and CBD revitalization projects.	Newly elected members open to ideas. Traffic management changes include new trees.
Water issues	WSUD-water quality Yarra River and Port Phillip Bay (Melbourne Water initiatives).	Water not such a high profile issue as in other cities.	Water availability a risk factor rather than policy driver. Rethinking practices to enable planting with water restrictions.	Bore water available for irrigation, but future limits probable

There is also variation in strategic policy drivers between cities. In Melbourne the lack of species diversity and the need to replace the city's ageing stock of European trees. In Sydney: responding to the constraints imposed by narrow, winding streets and tall buildings; building on past initiatives from 1988 and 2000; and improving on poor past selection, planting and establishment practices. In Brisbane the need is to provide year round shade and 'shade-ways', the need to provide greening as part of urban densifications; and the revitalization of the CBD and suburban centres. In Perth the need is for trees suited to the local climate and soils, and as part of the 'pedestrianization' of the city centre.

Water is also becoming a key strategic policy driver. In Melbourne drought and water restrictions have impacted on, and effected the management of, the city's traditional boulevards and parks planted with European tree species. WSUD is a key policy driver, with joint initiatives by Council and Melbourne Water to improve stormwater runoff to the Yarra River and Port Phillip Bay. WSUD is becoming part of the design ethic of the city. In Sydney water is not such a high profile issue as in other cities. In Brisbane water is seen as a risk factor rather than a policy driver, with a rethinking of practices to enable planting with water restrictions. In Perth bore water is available for irrigation, but futures limitations are probable. In most cities drought, water restrictions and other sustainability issues are creating a new policy layer, and a new design aesthetic.

Street tree management

Each city has a different set of policies for street tree planning and management, including street tree inventories, planting lists and more detailed master plans. Table 53 provides a summary of the different street tree management policies. Sydney probably has the most comprehensive set of policies in its *City of Sydney Tree Management Policies-Trees for a Living City*. (City of Sydney 2004). Perth has also recently produced a new comprehensive *Street Tree Framework* (City of Perth 2008). In Melbourne and Brisbane street tree policies are somewhat fragmented over a number of policy documents and guidelines. A key concern with street tree policies overall is that they do not simply focus on infill planting with ‘like with like’.

Table 53: Comparison between cities: street tree management

Topic	City			
	Melbourne	**Sydney**	**Brisbane**	**Perth**
Urban tree policies	Old *Tree Policy*. Suite of *Precinct Policies* (not for CBD)	*City of Sydney Tree Management Policies-Trees for a Living City.*	*Street Tree Policy Centres Design Manual.*	*Street Tree Framework.*
Streetscape policies	Program to enhance public life. *Grids and Greenery* 1980's (City of Melbourne 1987). Jan Gehl Study 1990's. Replicated 2004 (City of Melbourne 2004). Current *Urban Design Strategy-Public Melbourne* (City of Melbourne 2006). CBD materials palette guidelines. Sustainability now part of vision.	Policies follow on from 1988 Bicentennial and 2000 Olympics initiatives. 2008 Jan Gehl public domain study (Gehl 2008). Current *Sustainable Sydney 2030 Vision* process (City of Sydney 2008). Borrowed landscape in some streets.	*CBD Master Plan-* greening objectives (Brisbane City 2006a). *City Shape Program* densification and greening (Brisbane City 2006b). *Subtropical Boulevards Strategy* (Brisbane City 2006a). *City Signature Projects. Suburban Centres Improvements Projects* (SCIPS) (Brisbane City 2005).	*Public places Enhancement Strategy* (City of Perth 1997) under review. SAFER program (one-way to two-way streets). *Malls Action Plan* (City of Perth 2002a). *Malls Draft Concept Plan* (City of Perth 2002b). Review of *West Perth Urban Design Study* (City of Perth 1993).
Project delivery	Arboriculture in Parks and Recreation Unit, which is part of wider group with Urban Design (strategic) and Design Group (landscape architecture). Collaboration when streets restructured. Monthly streetscape committee meetings.	Arboriculture in Parks, Trees and Aquatic Facilities division, which is part of City Services. City Projects undertakes major streetscape projects with Parks Asset Manger (parks) or City Arborist (trees) as clients. Tree management team responsible for smaller projects and tree maintenance.	1. Council Vision, Corporate Plan and Lord Mayor's policies (strategic). 2. City Planning, and Natural Environment & Sustainability (main policy drivers). 3. Urban Design section (conceptual role and project oversight) (purchaser to City Design). Local Asset Services does on-ground delivery. 4. City Design -project documentation.	Urban Development Unit designs and builds projects (landscape architects, engineers and an arborist). Separate Strategic Planning Team. Parks & Landscape Services and Works & Services in Business Units Directorate. Operations section builds projects and installs trees.
Design standards	*Technotes*	*Technical Guidelines in Street Tree Master Plan*	*Centres design manual*	*Design and Construction Notes*
Additional funding sources	WSUD subsidies. Urban design and pedestrian amenity (based on Jan Gehl benefits).	Past landmark events 1998, 2000. Arterial traffic projects. *City of Villages* projects.	Attach to major transport projects. Also water, shade, public transport, active transport. Public-private partnerships. Demonstration projects. Trader levy.	
Other authorities	VicUrban (Docklands)	Sydney Harbour Foreshore Authority. RTA	Southbank Corporation.	East Perth Redevelopment Authority.

Street tree policies also interface with urban design and streetscape policies. Most Councils have strategies for the development of a high quality public realm in their CBD, usually emphasizing quality, consistency and durability in materials and detailing. Street trees may be seen as an important design element within this framework. In this sense Melbourne is probably most advanced with an ongoing program over the past 20 years to enhance public life in the city, beginning with *Grids and Greenery* (City of Melbourne 1987) in the 1980's, and Jan Gehl's valuable study in the 1980's (replicated in 2004) which quantified the benefits of an enhanced public realm (Gehl 2008), and the current *Urban Design Strategy-Public Melbourne* (City of Melbourne 2006). Melbourne has a consistent CBD design ethic and palette of materials, and sustainability is now becoming part of the vision. In Sydney streetscape initiatives have been more spasmodic, with significant design initiatives for the 1988 Bicentennial and 2000 Olympics. The current focus is on building on past initiatives, while creating a new *2030 Vision*, including a 2008 public domain study by Jan Gehl. In Brisbane a number of urban design initiatives include a greening component, including the *Brisbane CBD Master Plan* (Brisbane City 2006a), *City Shape Program* (Brisbane City 2006b), *Subtropical Boulevards Strategy* (Brisbane City 2006a) and *City Signature* and *Suburban Centres Improvement Projects* (Brisbane City 2005). Perth is currently reviewing a number of its urban design policies related to public spaces, to create a more pedestrian friendly CBD. A key initiative incorporating street trees is the *SAFER* program converting one-way CBD streets to two-way flow. It should also be noted that the demands for high quality, long-life materials (e.g. pavers), may create tree health and infrastructure conflict issues.

All Council's have some form of 'design standards' with standard tree planting and other details. While these help achieve consistency, they are not always compatible with the preferred approach that 'every site is different'.

Internal organizational structure and project delivery procedures also vary between cities. Arboriculture has traditionally been part of 'parks and gardens' departments, with an operational tree planting and maintenance focus. However in most cities it is now also part of the urban design policy and project delivery structure. Urban forestry may also be represented at the strategic, level as in Brisbane. Arborists may play a role in multi-disciplinary teams delivering streetscape projects incorporating street trees.

Street tree planting budgets may be limited, so all Council's adopt an 'opportunistic' model attaching tree planting to other projects and funding sources. These include major transportation, road reconstruction projects (Sydney, Brisbane, and Perth) and WSUD initiatives (Melbourne). It should also be noted that in each city, other government or semi-government authorities are responsible for tree planting on major urban redevelopment sites, which are subsequently handed over to

Council to manage. In some cases the tree planting actions of these bodies may not be in keeping with the objectives of the City Council.

Tree species selection issues

Each city has its own street tree heritage and history, and long established capital cities must deal with an established tree stock and planting palette. In Melbourne Planes (*Platanus* spp.) and elms (*Ulmus* spp.) in parks and boulevards, in Sydney Figs (*Ficus* spp.) in the larger parks, in Brisbane a mixed palette of evergreen subtropical species for year-round shade and flowering, and in Perth a number of species from the Perth region including *Eucalyptus* species and Willow Myrtles (*Agonis flexuosa)*. Each city must also plan for the replacement of ageing trees and avenues, which may require replanting with the same species, for heritage reasons, rather than more drought tolerant ones. A particular problem in CBD sites, is finding shade tolerant species for planting in narrow streets with high buildings, especially in Sydney, and in the narrower streets in Melbourne. Species tolerating periodic inundation are also required for WSUD sites.

All Councils are also attempting to diversify their planting palettes, to avoid the impact of any species-specific disease, and to fit tree species to a range of urban planting environments. However the Plane tree (*Platanus* spp.) remains dominant in all cities except subtropical Brisbane. Brisbane probably has the most species diversity, encouraging a mixed palette in its subtropical boulevards. Melbourne is investigating the contract growing of new species to overcome availability issues with the nursery industry. No Council has a strong 'native' tree policy, with most being a mix of native and exotic.

Each Council also has its 'problem trees' and preferred species. In Melbourne Oriental planes (*Platanus* x *orientalis*) are often too successful and damage hardscapes. In Sydney other authorities have inappropriately planted potentially large *Ficus* species in confined sites for 'instant effect'. In Brisbane palms are seen as providing no shade value. Perth has had problems with earlier plantings of *Lophostomen conferta* (Queensland brush box), *Corymbia maculata* (Spotted gum) *Ficus hillii* (Hill's fig) and Illawarra Flame Tree (*Brachychiton acerfolius*). In Melbourne *Waterhousia floribunda* (Weeping Lillypilly) is the preferred tree for narrow shaded streets, with *Zelkova serrata* (Japanese zelkova) and *Stenocarpus sinuatis* (Firewheel tree) the preferred replacement tree for other unattractive species such as *Gleditsea tricanthos* (Honey locust) *Fraxinus* spp. (Ash) and *Populus* spp. (Poplar) trees. In Sydney *Platanus orientalis* (Oriental plane) are planted in wider boulevards, with palms and poplars in the narrower shaded streets. Palms have also been planted to create streetscape themes in parts of the city. Preferred replacement trees include *Waterhousia floribunda* (Weeping Lillypilly) and *Flindersia australis* (Crows ash). In Brisbane the top five tree species are *Waterhousia floribunda* (Weeping Lillypilly), *Buckinghamia celsissima,* (Ivory curl flower), *Cupaniopsis anacardioides (*Tuckeroo), *Syzygium leuhmanii* (Small leaved Lillpilly), and *Tabebuia rosea* (Pink trumpet tree). In Perth P*latanus* x *acerfolia* (London Plane) is being widely planted, as it came top in a tree suitability matrix. *Melaleuca* species are also favoured, and a large number of palm species have been successfully planted at city gateways and entries.

Streetscape design issues

Lack of space, or 'contested space' is a key issue, especially limited footpath space in narrow streets. Lack of space is being exacerbated by other demands such as bike lanes, and the impacts on trees of reduced building setbacks. Councils generally try to plant the biggest tree possible, and provide the most space possible. Strategies in Melbourne include relocating trees from footpaths to the parking lane, and creating 'tree islands' in expanded median car parking spaces. In Perth the Council is attempting to widen CBD footpaths as part of road reconstruction for traffic management purposes. The biggest design issues appear to be in the narrower streets. In Melbourne footpaths are widened, and trees planted on side of the street only. Melbourne's laneway network is also due for renewal presenting opportunities for innovations in confined spaces such as pleaching, espalier and vertical landscapes.

Below ground design issues

In urban centres below ground constraints include extensive underground services and below ground structures such as car parks, and in Brisbane bus stations. Councils generally try to provide the most planting volume possible. Brisbane sees this as a major issue at the arboriculture/design interface, with required volumes depending on maintenance inputs, and with better information needed on required soil volumes. Brisbane has carried out the pioneering work in Australia on increasing rooting volumes with soil trench technology. 'First generation' projects comprised a locally designed structural soil mix using large rock spalls (60% of the mix rock spalls, 40% soil filled voids). These reduced rooting volumes led Council to develop 'second generation' projects with 100% growing medium, using suspended concrete slabs with an air space between the soil and the underside of the slab. In Brisbane soils are installed in two layers with different shrinkage properties, the top 30 cm layer with more organic content being better aerated and easily topped up in open planting situations. While *AS4449* specifies a range of soils, it is considered that more detail is required. Other cities have also installed structural soils in continuous trenches or tree pit extensions. However Perth highlights the limitations of continuous trenches due to underground services (including cross-services), except on vacant sites. Perth is also interested in pursuing the most recent technology of installing a matrix of plastic load bearing soil cells. All Councils also have examples of containerized trees, both above and below ground, however some earlier designs have suffered from restricted soil volumes combined with irrigation restrictions.

With respect to the tree pit surface, Melbourne and Sydney are currently using resin bonded gravel (Terrabond™). In Melbourne it is being used as a replacement for granitic sand in the CBD, which experienced problems with street sweeping machines spreading sand onto footpaths and into stormwater drains. In Sydney it is currently being used in preference to the granite sett detail, preferred by the City's landscape architects, which has been subject to settling failure. Resin bonded gravel comprises a difference of opinion between arborists and landscape architects, of functionality versus aesthetics, with the aesthetics of resin bonded gravel in formal paved urban streets being questioned. However a range of stone sizes, colours and textures can be selected to suit the streetscape context. In Sydney 'unfriendly bases' are to be avoided, and ideally installation of the base should be delayed 6-12 months to allow for settlement and to improve water penetration during establishment. Councils are also aware of resin bonded gravel issues including cost, need for dry conditions for installation, and shrinking and settling issues. Both Brisbane and Perth install signature tree grates, suspended on a metal frame, and with provision for future widening of the trunk opening. In Brisbane these have been seen to create slip and trip hazards if installed in a public space, rather than at edge of kerb.

Water management issues

Drought and water restrictions are impacting on established urban trees. In Melbourne past irrigation practices have encouraged root growth. Council is investigating new approaches to watering urban trees, such as the use of water filled road barriers to irrigate elms (*Ulmus* spp.) in Birrarung Mar. In Perth water restrictions are not as severe as in other states, due to the availability of bore water for irrigation, but its long term viability is an issue. Council has developed a bore water storage lake on the foreshore. Both Perth and Melbourne Council's have scaled down expectations of greenery and watered turf, with watering directed to priority sites, and replacing grassed medians and verges with granitic sand or native grasses. The use of wetting agents and water saving crystals is also being investigated.

Water Sensitive Urban Design

WSUD is now seen as driving the design ethic in Melbourne, with WSUD being focussed into wider streetscape projects (part-funded by Melbourne Water). However WSUD is not considered such a high priority in Sydney or Perth. In Sydney there are more limited opportunities due to topography, limited space and surrounding infrastructure. Perth experiences long dry spells between heavy rainfall events, and has sandy soils with low water holding capacity, which has lead to few WSUD installations. Issues with 'first generation' bioretention tree pits in Melbourne include high installation (retrofitting) and maintenance costs. These include the cost of hard engineered infrastructure around the pit, and cost of connection to the existing stormwater system. An early bioretention tree pit, trailed in Sydney's Kings Cross, was not carried through to other streets due to water quality issues and an overly complex design.

These first generation projects provided indirect (watering) benefits to trees. The City of Melbourne is now looking at simpler and less expensive passive watering designs that will add value to tree pits with enhanced water retention and infiltration, and with runoff quality benefits even if not connected to the stormwater system. One such system is being trialled in Perth. Permeable paving is another WSUD initiative beneficial to street trees, but has not been installed in CBD situations such as Melbourne with a design ethic requiring uniform bluestone pavers.

Infrastructure issues

In Melbourne Council is aware of the adage 'when the tree succeeds the infrastructure fails, when the infrastructure succeeds the tree fails'. In the CBD bluestone paving is installed on a concrete slab, impacting on tree roots. The position of the tree relative to the kerb is also related to tree damage and kerb replacement. Typically tree roots have been found to follow the (watered) verge impacting on bluestone kerbs, and also grow under footpaths onto private property necessitating root barrier installation. In Perth tree trunks must be setback 1200 mm from the kerb face.

Below ground services are a limiting factor in all cities. However on 'clean slate' sites services can be provided with a trench for combined services. In Sydney services often require moving, lowering or root barrier installation (even if 'symbolic' only). Council is also installing new SmartPoles® that require larger footings, located in the tree root zone. In Brisbane major projects require unavoidable and costly service relocations, however fibre optics are a 'nightmare' and too costly to relocate. With respect to overhead services, Sydney is installing aerial bundled cable to reduce pruning impacts, and undergrounding power in major streetscape upgrades. In Brisbane, removing powerlines increases design scope. In the past power was undergrounded, but with increased costs cables are now installed for future undergrounding.

Implementation issues

In Brisbane Lyndal Plant advocates the following general approach. First justify the need for trees in new development and urban renewal, an holistic approach based on livability. Second, create space for trees, based on arboricultural principles. Spatial allocation is a critical factor, including definition of minimum space requirements. And third make the tree work in that space, by providing the right qualities to optimize the benefits. In essence, a site by site approach is required.

Successful projects also require political and community support. Resident consultation is a key requirement in street reconstruction projects and in Melbourne Council uses sophisticated 3D simulations to communicate street improvement outcomes. In Brisbane Council has a good understanding of the need for trees based on community surveys. Opportunities for tree planting, however, may be limited in capital city centres, as there are few greenfield sites, new streets or street redevelopments. In Brisbane there are economic limits on streetscape improvements, which can be overcome if not presented as new capital projects, but rather as part of major road projects, water, active transport, and economically driven projects.

Planting and establishment issues

The City of Sydney has had experiences with inappropriate tree planting practices in a number of recent major road upgrade projects. Sydney plants a minimum 100 litre tree in the suburbs, and 200 litres in the CBD, allowing trees to clear pedestrian head height more quickly, and reduce rates of casual vandalism. The preference is not to plant trees in summer, but mainly in autumn through to October. In larger streetscape projects it is preferable to plant trees some time after the roadworks are completed, to allow planting in the appropriate season, however this is not always possible due to the need to deliver completed projects by a specified date. Incorrect planting depth was an issue in the Oxford Street and William Street projects, and incorrect practices by contractors continue, such as lack of hand watering of the rootball. In the William Street project a large number of trees planted by the road traffic authority failed due to incorrect planting and maintenance, which were therefore removed and replaced. Council has instigated a new maintenance system involving more frequent maintenance visits for a minimum two year period, before reverting back to the normal maintenance cycle. In addition some tasks which were the responsibility of contractors have reverted back to the maintenance team.

Summary of practices

Table 54, Table 55 and Table 56 and provides a final summary of the different practices identified in the Australian Capital Cities Study.

Table 54: Capital city practices: above and below ground design

Practice	Comments	
Above ground design		
Footpath widening	General	Streetscape policy (Perth)
	Marginal widening	George Street, Redfern Street (Sydney)
	Remove one traffic lane	Oxford Street, William Street (Sydney) Melbourne Street (Brisbane)
	Remove two traffic lanes	Swanston Walk (Melbourne) CBD, William Street (Perth) Albert Street (Brisbane)
	Widening one side only	'Little' Streets (Melbourne)
Planting one side only	Narrow streets	'Little' Streets (Melbourne) Acland Street(Melbourne)
Planting at property boundary	Next to property	Woolangabba-proposed (Brisbane)
Planting in parking lane	In buildout	WilliamStreet (Sydney)
	In road surface-with wheel stops	Redfern Street (Sydney)
	In road surface-with bollards	Acland Street (Melbourne)
More than one tree row	Parking lane+verge+property boundary	Woolangabba-proposed (Brisbane)
Median planting	Different species to verge	Grey Street (Brisbane)
	Tree islands with centre road parking	CBD wide traditional (Melbourne)
	Enlarged tree islands	CBD wide (Melbourne)
	Contra-flow bike lane	King Street (Sydney)
	Raised median	Melbourne boulevards
Alternative to traditional avenue	'Subtropical boulevard"	Melbourne Street, Albert Street (Brisbane) Roma Street-proposed
	Informal spacing	Melbourne Street (Brisbane)
	Mixed species	Melbourne Street (Brisbane)
	Underplanting	Melbourne Street (Brisbane)
	Opportunistic group planting (residual spaces created by road realignment)	Melbourne Street Square (Brisbane)
Multi-way boulevard	3 separated carriageways	St Kilda Road (Melbourne)
Group planting	Block planting	City Gateway (Melbourne) Docklands (Melbourne)
Shade structures	Over footpath	Grey Street Southbank (Brisbane)
Vertical landscaping	Green walls	Proposal-laneways (Melbourne)
	Espalier, pleaching	Proposal-laneways (Melbourne)
Below ground design		
Increased volumes	Enlarged tree pit	Collins Street (Melbourne) Hay Street Mall (Perth)
	Calculated soil volumes	Albert Street (Brisbane)
	Root trench	Albert Street (Brisbane)
Structural soil	Tree pit extension	William Street (Sydney)
	Continuous root trench	Queen Victoria site (Melbourne) William Street, King Street (Sydney)
	Continuous root trench in footpath	Albert Street (Brisbane)
	Continuous root trench in parking lane	Redfern Street (Sydney) Roma Street Parklands boulevard (Brisbane)
Suspended pavement	Pavers on reinforced slab	Darlinghurst Road, Oxford Street (Sydney) Melbourne Street, George Street (Brisbane)
	Pavers on slab on metal frame	Hay Street Mall (Perth)
	Timber deck on metal frame	Pitt Street Mall (Sydney)
	Root trench	George Street (Brisbane)
	Tree pit extension	Oxford Street (Sydney)
	With air cavity	Darlinghurst Road, Oxford Street (Sydney)
Structural root cells	In footpath	Stanley Street-proposed (Sydney)
	In parking lane	Stanley Street-proposed (Sydney)
Raised planter bed	On deck	Bourke Street Mall (Melbourne)
	Open to soil	Southbank (Melbourne)
Containerized	Above ground	Southbank (Melbourne) Queen Street Mall (Brisbane)
	Below ground (tree vault)	Collins Street Bridge (Melbourne) Pitt Street Mall (Sydney)

Table 55: Capital city practices: tree pit surfaces and water management

Practice	Comments	
Tree pit surface		
Granitic sand		Melbourne Square (Melbourne)
Resin bonded gravel	Plain	CBD wide (Melbourne) St Mary's Road (Sydney)
	With granite setts	Standard detail. College Street (Sydney)
	With rubber at tree base	Oxford Street (Sydney)
Tree grate	Metal suspended on metal frame	Redfern Street (Sydney) Signature tree grate (Perth) Signature tree grate (Brisbane)
	Granite suspended on metal frame	Queen Street GPO (Brisbane)
Suspended pavement on metal frame	Paving	Darlinghurst Road, Oxford Street (Sydney)
	Timber deck	Pitt Street Mall 9Sydney)
Underplanting	In-ground	Murray Street Mall (Perth) Melbourne Street (Brisbane)
	In removable planters	Queen Street Mall (Brisbane)
Moveable planter boxes	Surrounding tree pit	Hay Street Mall (Perth)
Water management		
WSUD		
Bioretention basin	In buildout	Cremorne Street (Melbourne)
Bioretention tree pit	In footpath	Little Bourke Street, Little Collins Street, Bourke Street Docklands (Melbourne) Darlinghurst Road-trial (Sydney)
	In parking lane	Acland Street (Melbourne)
	Integrated with seating	Batmans Drive Docklands (Melbourne)
Bioretention edge treatment	Fence	Cremorne Street (Melbourne)
	Seating	Batmans Drive Docklands (Melbourne)
	Slope	Docklands (Melbourne)
Raingarden	Raised	Davisons Lane (Melbourne)
Bioretention swale	In median	Victoria Park (Sydney)
	At verge	Batmans Drive Docklands (Melbourne)
Stormwater inlet-planting in road	From water table	Melbourne Street (Brisbane)
	Permeable kerb	Victoria Park (Sydney)
	Lowered surface	Redfern Street (Sydney)
Stormwater inlet-tree in footpath	Kerb inlet-in water table	Northbridge Pizza (Perth)
	Modified kerb inlet	Melbourne Street (Brisbane)
Roof runoff	Downpipe with spreader	Davisons Lane (Melbourne)
Passive irrigation	Tree in road surface-lowered	Bellair Street (Melbourne) Redfern Street (Sydney)
	Infiltration trench in verge	Harris Street-proposed (Melbourne)
	Subsurface irrigation ring	Stanley Street-proposed (Sydney)
	Tree in footpath with kerb inlet	(Nortbridge Piazza) Perth) Melbourne Street (Brisbane) Woolangabba-proposed (Brisbane)
Underground storage and reuse		Melbourne Street (Brisbane)
Other water management		
Water filled road barriers		Birrarung Mar (Melbourne)
Alternative water sources	Bore water	Lake Vasto bore water storage (Perth)
	Recycled waste water	
Pervious surfaces	Permeable pavers	Woolangabba-proposed (Brisbane)
	Perforated pavers	Martin Place-unsuccessful (Sydney)
	Other porous surface	Pasley Street-proposed (Melbourne)
Water saving crystals		To be investigated (Perth)
Turf alternatives for verges	Turf removal	Policy (Perth) Policy (Melbourne)
	Granitic sand	Melbourne
	Native grasses	Melbourne

Table 56: Capital city practices: infrastructure and tree species

Practice	**Comments**	
Infrastructure		
Hardscape		
Separate tree and hardscape	Enlarged cut-out	Collins Street (Melbourne)
	Tree trunk set back from kerb	Standard detail (1200 mm) (Perth)
	Tree pit lowered below hardscape	Oxford Street, Darlinghurst Road (Sydney) Hay Street Mall (Perth)
Avoiding road collapse	Tree pit set back from kerb	Standard detail (Perth)
3D root barrier	Aggregate base for unit pavers	Alexander Library (Perth)
Pavement design	Shallow profile	Collins Street-proposed (Melbourne)
	Flexible (rubber)	Proposal (Melbourne)
Services		
Power lines	Aerial bundled cable	City wide. Riley Street (Sydney)
	Undergrounding	Major projects (Brisbane)
	Cable for future undergrounding	Policy (Brisbane)
Service relocation/ lowering		Major projects (Brisbane) Little Bourke Street (Melbourne)
Planting over underground services	In-ground containers	Howard Street, Sherwood Street-limited life(Perth)
	Raised planter beds	Forrest Place Darlinghurst Road, Oxford Street (Sydney)
Removable furniture over services	Precast	Melbourne Street (Brisbane)
Veranda cutbacks	Co-ordinated cutback program	Oxford Street (Sydney)
Tree species selection		
Shade tolerance	Narrow streets	Waterhousia-Little Streets '(Melbourne) Palms-Chifley Square, northern CBD (Sydney) Poplar-Kent Street (Sydney)
Inundation tolerance	WSUD installations	Zelkova-Acland Street (Melbourne)
Mature tree transplanting		Palms-Northbridge Piazza (Perth)
Mixed species in a street		Melbourne Street (Brisbane)

10 National Practitioner Study

10.1 Introduction

As part of the mixed methods approach, a quantitative online survey was undertaken in 2008 to obtain a 'snapshot' of the attitudes and practices of street tree practitioners throughout Australia. The survey was targeted primarily at staff working in tree related fields within local government organizations. It was intended that the quantitative survey be followed up with in-depth interviews to further investigate the issues identified.

10.2 Methodology

Survey research

Questionnaire based survey research is one method of data collection in quantitative correlation research (Groat & Wang 2002). The aim of survey research is to provide a quantitative or numerical description of some characteristic of a sample of a population, and from that sample make inferences about the wider population (Babbie 1990). Survey data collection can take a number of forms including self administered questionnaires and structured record interviews. Surveys may also be internet based, administered online (Nesbary 2000; Babbie 2001). Advantages of mail or internet based surveys include the ability to conveniently and economically collect a large amount of data from a large number of people in a limited time (Fowler 2002). However convenience and economy may come at the cost of a lack of in-depth understanding of the issues surveyed (Groat & Wang 2002). In this study online survey research was used to establish a broad picture of issues over a wide geographic population, and was followed up with in-depth interviews to develop a deeper understanding of those issues.

Online survey

The survey instrument was developed and administered using Survey Monkey online software (http://www.surveymonkey.com/). The researcher subscribes to the service, and an online questionnaire is developed using standardized questionnaire formats. An invitation and link to the online questionnaire can then be placed on a website, or distributed electronically via email (either by the researcher or by Survey Monkey). The software provider also collects survey responses and tabulates the data in spreadsheet and summary format. Advantages of online surveys include ability of respondents to complete the survey in their own time, or in their workplace, and anonymity (Brace 2004). It is also less expensive and quicker to convey to respondents than paper based mail out surveys. Typically many people will respond within a day of receiving, and there is often a large response on the day the invitation is sent (Yun & Trumbo 2000). Online surveys are also 'dynamic' in that responses can be analyzed statistically on a continuing basis as they are received. Partially completed questionnaires can also be analyzed. Online surveys also allow easier use of ‘skip logic’ than paper based questionnaires, where respondents can click a ‘next’ button to go to follow up questions. It is also possible to track responses in terms of who has and has not responded (Sheehan 2001). Disadvantages include time restraints on questionnaire length, and ethical issues of personal intrusion by sending unsolicited emails (Yun & Trumbo 2000). Email messages may also be rejected as SPAM. Survey Monkey has an anti-spamming agreement and an opt-out link field in its email invitation allowing the recipient to opt out of the mailing list. Another concern is the ability of a respondent to fill out multiple questionnaires, including logging on as a different user. This was not considered to be a significant concern for this survey due to the nature of the questions and the targeting of the survey to specific groups. It was not considered that there was any motivation for respondents to attempt to bias the survey results. Respondents were assured of anonymity and confidentiality, however there was an option for the respondent to provide personal details if desired. Of the total respondents 89.5 percent voluntarily provided their name and 96.5 percent the name of their organization, allowing for checking of the validity of responses if required.

Survey instrument

The survey instrument consisted of an online questionnaire. The questionnaire was designed to collect as much information as possible within the time constraints of an online format. Questions were a mix of multiple-choice, rating scale and open-ended formats. (A sample questionnaire is provided in Appendix A1). Questions were presented in the following sequence:

- Introductory message.
- Part A-Details of individual and organisation.
- Part B-Attitudes to a range of street tree issues.
- Part C-Use of a range of street tree practices.
- Closing message.

Respondents were invited to provide their name and contact details, but this remained optional. When emailed to respondents or placed in an organization’s electronic newsletter, the survey link and invitation to respond were accompanied by an explanation of the aims of the research project and contact details for any queries (Refer Appendix A2). All questions were optional, and partially completed questionnaires could be submitted, and were included in the data analysis. The questionnaire was first developed in paper form and pilot tested with key respondents. The online survey was also pretested electronically prior to final posting online.

Ethics approval

Approval of the survey methodology and questionnaire was obtained from the University of Adelaide Ethics Committee. The online questionnaire included University of Adelaide and

TREENET letterhead, with TREENET actively supporting the survey. Respondents had the option of providing their names and contact details, and were advised that the survey results would remain anonymous and confidential.

Survey distribution

The survey was administered through a variety of means aimed at the target population of local government arborists and landscape architects, as well as planners, engineers and asset managers. These included:

- Emailing the survey link to potential respondents listed in available data bases, with an invitation to respond to the survey.
- Placing the survey link in online newsletters distributed by professional bodies to their memberships, with an invitation to respond.

Survey links were distributed through the following organizations.

- TREENET data base (222 Local Government members).
- AILA (Australian Institute of Landscape Architects) electronic newsletter and website.
- PIA (Planning Institute of Australia) electronic newsletter.
- ALGA (Australian Local Government Association) electronic newsletter.
- LGMA (Local Government Manager's Association) electronic newsletter.
- ISAAC (International Society of Arborists Australian Chapter) electronic newsletter.
- Engineers Australia electronic newsletter.

The survey provided a means of collecting data from a sample of the wider population, which comprised local government tree managers and others in local government involved with planning for urban trees. As such the total population size was not known. While data bases do exist for certain groups, such as arborists, landscape architects, and planners, these are confidential and do not necessarily identify those working in local government. A 'cluster' sampling approach was adopted which can be used where it is impossible or impractical to compile a list of the wider population, and the population within groups or organizations is sampled (Babbie 2001). Therefore, with the exception of the TREENET data base, the survey link was distributed via each organizations electronic newsletter. This comprises a 'convenience' sample, based on availability of respondents, rather than a completely randomized sample.

Survey response

The highest rates of response occurred in the week immediately following the online distribution of each survey link. Follow up invitations were also contained in subsequent electronic newsletters.

Personal follow up reminders were also sent where non-respondents could be identified, as in the TREENET database. 282 participants began the survey, with 261 completing it (92.6%). It should also be noted that useable data can also obtained from partially completed questionnaires.
The Survey Monkey software enables identification of responses by the different 'collector' tools. Table 57 summarizes responses from the different 'collectors'. With the exception of the TREENET mail out, the total population being surveyed (potential responses) remained unknown. This was due to the fact that the organizational data-base being surveyed either remained confidential (the organization maintained a database but protected its confidentiality), or was unknown (the organization maintained a membership data-base, but the potential respondent sample could not be identified within that broader data-base). The wide online distribution of the survey also meant that other non-targeted individuals could submit responses if they desired.

Table 57: Survey response by collector

Collector	Number of responses	Potential responses
TREENET	136	222
AILA	69	Unknown
Other	77	Unknown
TOTAL	282	Unknown

It must be acknowledged that the survey will necessarily have a 'pro tree' bias, being distributed primarily to those dedicated to urban tree planning and management, and with an interest in street tree issues. However the aim of the survey was to assess the attitudes of local government tree managers rather than the wider population. One respondent suggested that it would be of value to administer the survey to a range of other 'non tree' professions and groups.

Data produced by the survey were analysed using simple descriptive statistics including tables and charts generated by the online provider. Initial analysis was based on the total sample of 282 responses (with the actual number of responses varying between questions). Further analysis could also be undertaken by State, or by discipline; however this would involve making inferences based on smaller samples.

Response by State

Survey responses were obtained from all Australian States. Table 58, Figure 29 and Figure 30 summarize responses from each State by individuals and by organizations (with some organizations providing more than one response). It should be noted that although the survey was anonymous some respondents still did not provide details of their location or organization.

Table 58: Survey response by State

State	No. of responses (individuals)	No. of responses (organizations)
NSW	74	36
Vic	66	35
SA	71	26
Qld	26	12
WA	15	9
Tas	6	3
NT	2	2
ACT	1	1
Total	261	109

The highest number of responses was from the two most populous States. The relatively high proportion from South Australia was most likely due to higher local awareness with the survey being South Australian based. Relatively low responses from Queensland may be due to the fact that the whole of the Brisbane metropolitan area is administered by a single ‘greater metropolitan’ Council (population over one million). Local government amalgamations also occurred in Queensland during the course of the survey. The potential widespread distribution of online surveys was confirmed with several unsolicited responses from overseas (not included in the analysis).

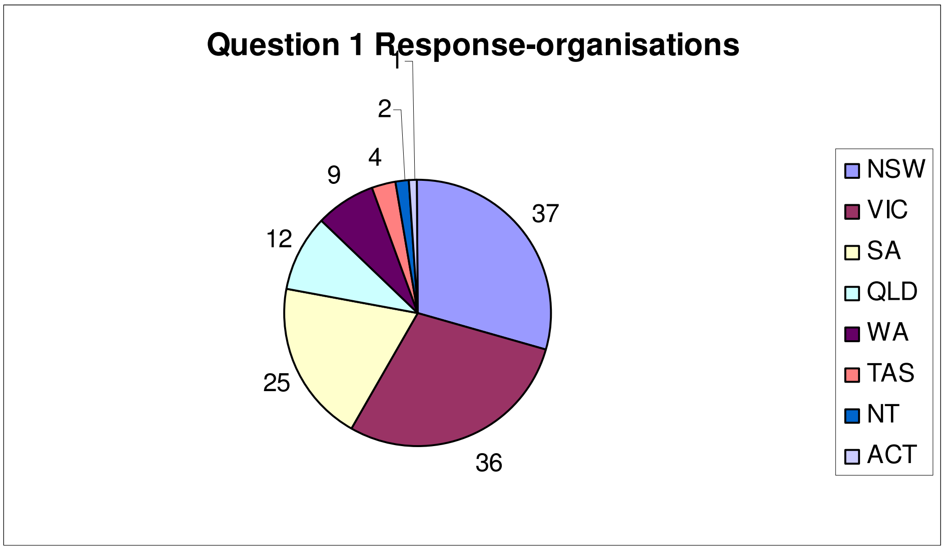

Figure 29: Survey response by State (organizations)

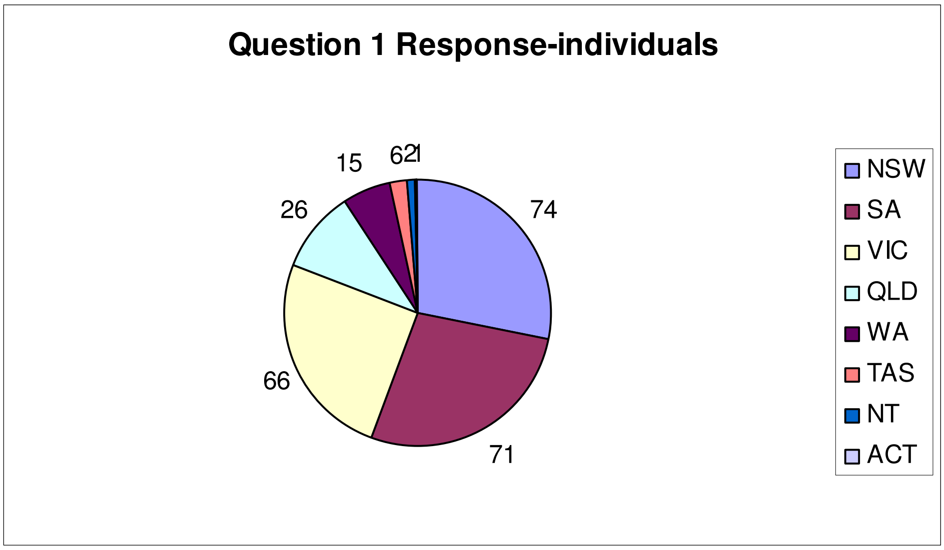

Figure 30: Survey response by State (individuals)

A detailed tabulation of local government and related organizations which responded to the survey is presented in Appendix A3. It is considered that this represented a reasonable geographic coverage in the larger states, including all capital cities and many of the larger urban and regional centres.

Response by discipline (qualifications)

The primary qualifications of respondents, presented in Figure 31, were taken as an indication of their professional discipline. Some respondents also had a secondary qualification, not included in the diagram). The largest response was from the targeted groups of arboriculture/horticulture (148 or half of respondents) and landscape architecture (68 or one quarter of respondents). There were relatively fewer responses from planners (36), engineers (14) and others (15), despite the survey being distributed through their professional bodies. This may be indicative of a higher level of interest in the topic amongst 'pro-tree' professions such as arborists and landscape architects, with relatively little interest by groups such as engineers. The 'other' category included a predominance of science-based qualifications (10) such as natural resource management.

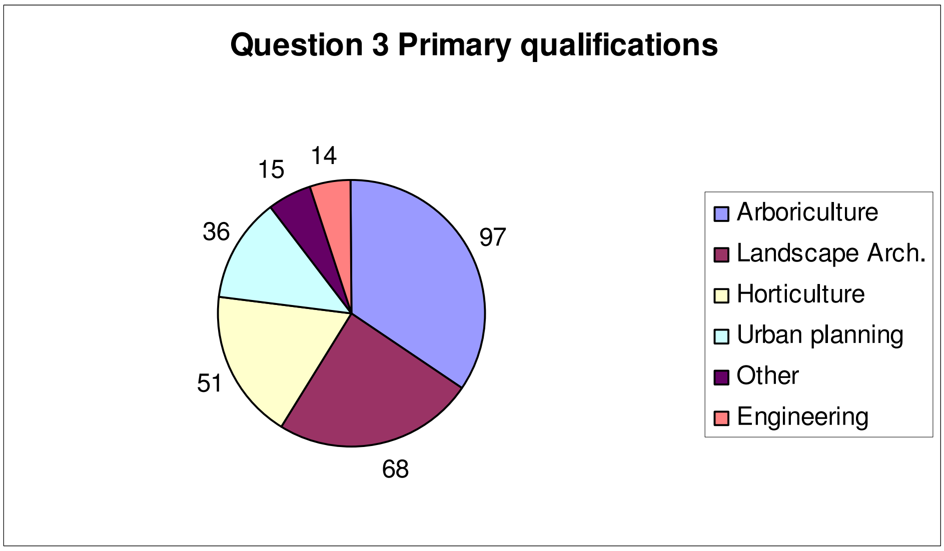

Figure 31: Survey response by primary qualifications

10.3 Respondent attitudes and perceptions

Questions 7-10 asked respondents about their attitudes and perceptions of a number of street tree topics. Respondents were asked rate their responses on a scale of 1-5. The following figures present this data in the form of rating averages for each question, for all respondents who answered that question. Provision was also made for open-ended responses, which are summarized in the text. A full tabulation of open-ended responses is also contained in Appendix A4. In the following sections the findings from each question are discussed and conclusions drawn. A comparison was also made of the responses of individuals identified in the survey as either landscape architects (68) or arborists (98) to give an insight into any possible differences in perceptions between the two disciplines.

10.3.1 Benefits

Current street tree literature emphasizes the many benefits delivered by street trees, with emphasis on both their human health and well-being benefits, and the more quantifiable ecological services they can provide. Respondents were asked to rate the benefits of street trees on a scale of 1-5. The intent of the question was to attempt to quantify the priorities given by respondents to the different categories cited in the current literature on urban and street trees benefits. Figure 32 presents rating averages for all 262 respondents who answered the question. Figure 33 presents a more detailed analysis of responses to the question.

Figure 32: Perceived street tree benefits

How do you rate each of the following possible benefits of street trees, from least (1) to most (5).							
Answer Options	**1**	**2**	**3**	**4**	**5**	**Rating Average**	**Response Count**
Environmental	1	8	15	67	169	4.52	260
Ecological	3	17	43	74	123	4.14	260
Pedestrian amenity	3	5	20	90	140	4.39	258
Visual/aesthetic	3	2	8	57	191	4.65	261
Economic	8	29	68	80	74	3.71	259
Social/psychological	4	6	14	80	128	4.39	232
Other(please specify below)							31
						answered question	**262**
						skipped question	**20**

Figure 33: Detailed responses: question 7

Discussion

As expected, respondents, being well informed on the topic, gave high ratings to street tree benefits for all categories. Despite recent emphasis on the quantifiable environmental benefits of trees, their less tangible visual and aesthetic roles were still rated highest. Ecological and economic benefits rated lowest (although still high), possibly due to the varying ecological value of urban tree populations, and the less well researched nature of economic benefits.

Open ended responses (31 responses)

Respondents referred to the many benefits of urban trees. A key environmental benefit is shade and reduction of the urban heat island effect. Shade is also an important factor in creating urban amenity. Ecological benefits are dependent on species and location. Economic benefits include increased property values. Social and psychological benefits include traffic calming effects. Cultural and heritage values are also significant and could be included as a separate benefit category. The issue of anti-tree attitudes of some residents was also raised, and lack of awareness of benefits by the community.

Comparison of landscape architects and arborists.

Figure 34 presents responses of landscape architects (68) and arborists (98) to give an insight into any possible differences in perceptions of street tree benefits between the two disciplines. The ranking of benefits is the same for the two groups, with landscape architects providing a slightly higher rating in all categories except economic benefits.

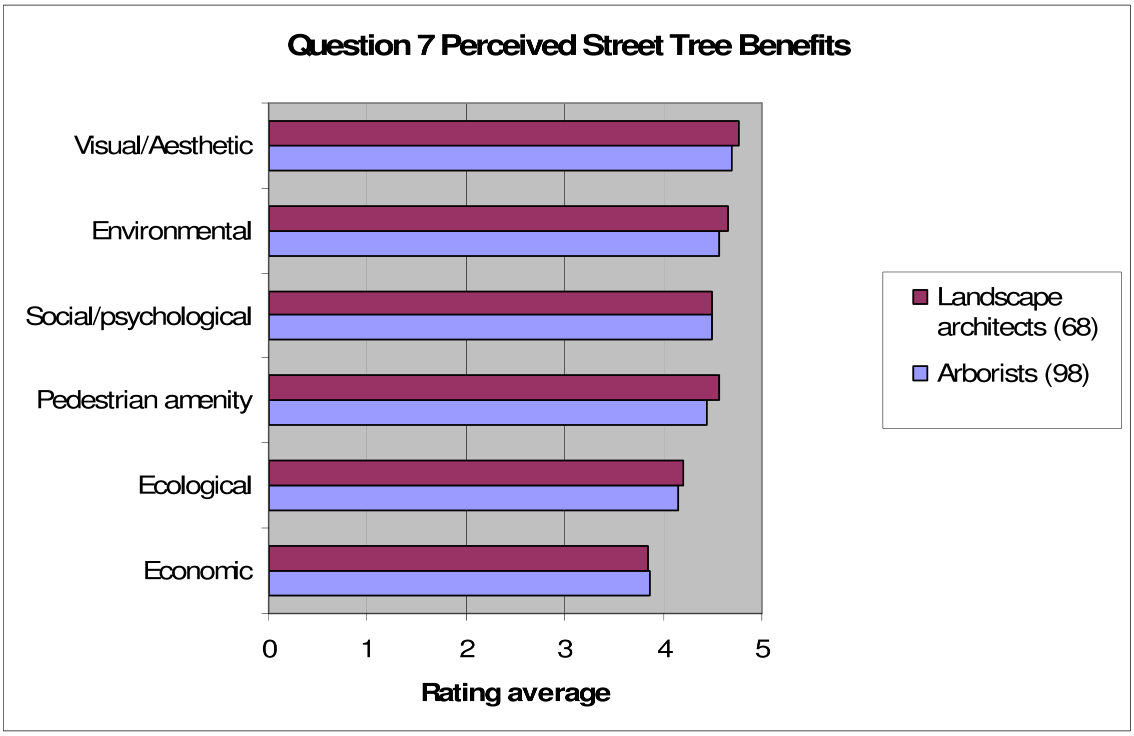

Figure 34: Perception of street tree benefits by landscape architects and arborists

Conclusion

In recent years a large body of literature has developed on the benefits of street trees and the urban forest (Clark & Matheney 2009. This has emphasized the environmental benefits of trees in terms of quantifying the ecological services they can deliver (Nowak & Dwyer 2007). Most of this has been quantitative research undertaken by arborists and related scientific disciplines (McLean *et al.*). In part this can be seen as an attempt to 'legitimize' the value of trees as urban infrastructure in the eyes of engineers and asset managers, to prove that trees are more than just 'aesthetic decoration' in a street. This also reflects a shift in urban tree management paradigms from creating 'urban amenity' to one of risk and asset management. An interesting outcome of the survey is that, while the environmental benefits of trees are well recognized, the main perceived benefit is their visual/aesthetic role. This aspect is less tangible and less easily quantified, and little research has been undertaken by those well versed in the field of urban aesthetics and 'place making'. However the visual, aesthetic and place making role of trees in cities is very real.

10.3.2 Issues

As well as delivering a range of benefits, there are also a number of issues, problems and on-going costs associated with planting and maintaining the urban forest. Respondents were asked to rate the issues associated with street trees on a scale of 1-5. The intent of the question was to attempt to quantify respondents perceptions of urban street tree related issues based on the main issues identified in the literature review, and with provision for additional open ended comments. Figure 35 presents rating averages for all 257 respondents who answered the question. Figure 36 presents a more detailed analysis of responses to the question.

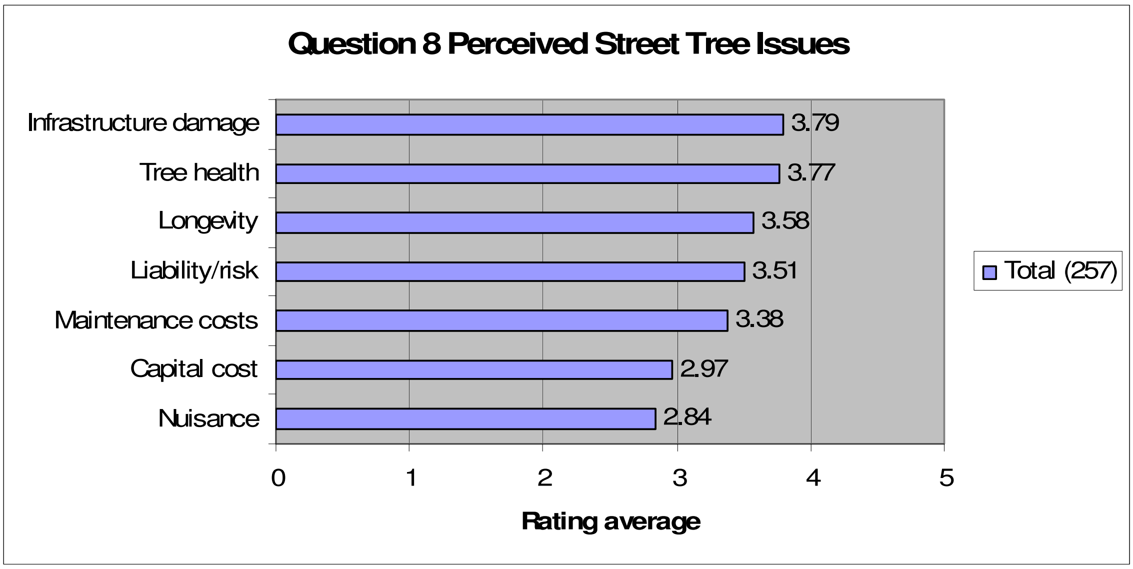

Figure 35: Perceived street tree issues

How do you rate each of the following possible issues or problems involving street trees, from least (1) to most (5)?							
Answer Options	**1**	**2**	**3**	**4**	**5**	**Rating Average**	**Response Count**
Poor tree health	6	23	56	109	61	3.77	255
Reduced tree longevity	9	28	79	85	55	3.58	256
Infrastructure damage	10	27	54	80	84	3.79	255
Street tree nuisance	41	69	59	56	27	2.84	252
Liability/risk	9	49	64	67	64	3.51	253
Capital costs	23	74	69	65	24	2.97	255
Maintenance costs	12	49	69	81	42	3.36	253
Other (please specify below)							28
						answered question	**257**
						skipped question	**25**

Figure 36: Detailed responses: question 8

Discussion

Respondents generally rated street tree issues and problems less significantly than benefits. Infrastructure damage was rated as the main issue, which also relates to the other significant issues of tree health and longevity. Capital costs and nuisance were seen as the least significant. Liability was rated as a more significant issue than nuisance, with tree managers possibly seeing tree nuisance as a perceived rather than real problem. Ongoing maintenance costs were seen as more significant than capital costs.

Open ended responses (27 responses)

Infrastructure conflicts in urban areas included below ground and overhead services and buildings. Soil compaction is also implicated in infrastructure damage and declining tree health. Risk and nuisance are seen as both real and perceived issues. Urban development in general is also an issue. Poor management practices were noted as of more significance than limited budgets, which could be included as a separate issue. Once again the issue of negative community perceptions of trees was raised. It was suggested that increased awareness of benefits could help offset negative community attitudes to trees.

Comparison of landscape architects and arborists.

Figure 37 presents responses of landscape architects (68) and arborists (98) to give an insight into any possible differences in perceptions of street tree issues between the two disciplines. Differences can be observed in the ranking of issues by the two groups. While arborists gave the highest ranking to tree health and longevity, landscape architects ranked infrastructure damage and public liability the highest. This may be due to the landscape architects involvement in the design of the ‘hard landscape’, with the arborist’s main focus on the tree. In all categories except infrastructure damage and liability, landscape architects gave a lower rating to each issue than arborists. This may be due to the fact that the landscape architect tends to be less involved with longer term tree issues and street tree management, their role often ending once the tree and streetscape have been installed and established.

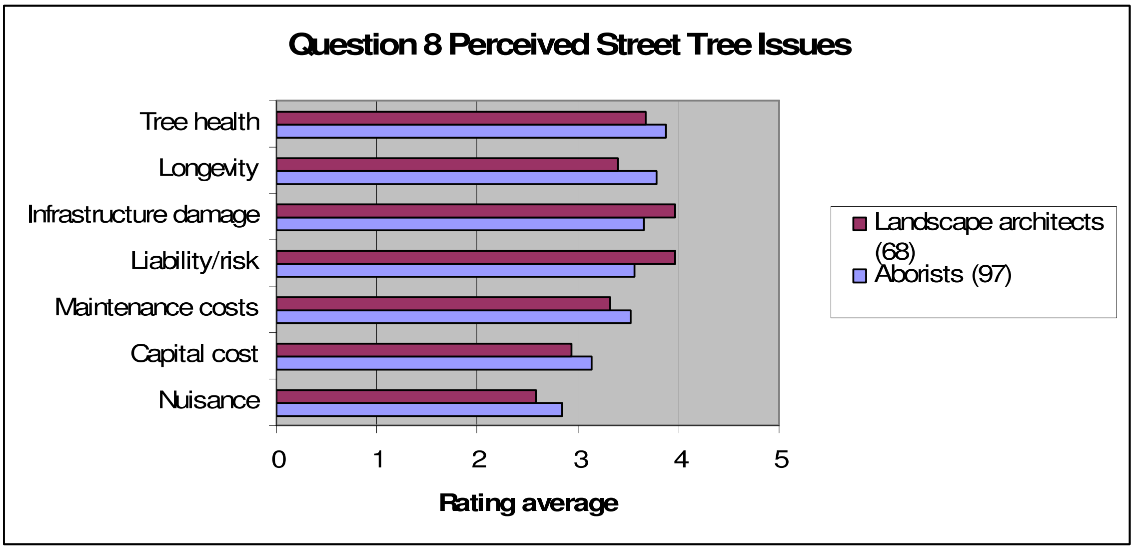

Figure 37: Perception of street tree issues by landscape architects and arborists

Conclusion

The survey confirmed the findings of the literature review that infrastructure damage is a significant and universal issue for urban tree managers (Costello & Jones 2003), and that tree health and longevity are key concerns in urban settings (Urban 2004). Concerns for liability and risk also reflect the current paradigm of street tree management which has evolved from urban amenity to risk and asset management (Norris 2005).

10.3.3 Constraints

The urban environment comprises a hostile environment for the planting and establishment of urban street trees, which may be exacerbated by unsustainable planting practices. Respondents were asked to rate the constraints on street tree establishment, on a scale of 1-5. The intent of the question was to attempt to quantify respondent's perceptions of the constraints on urban street tree planting and establishment identified in the literature review, and with provision for additional open ended comments. Figure 38 presents rating averages for all 260 respondents who answered the question. Figure 39 presents a more detailed analysis of responses to the question.

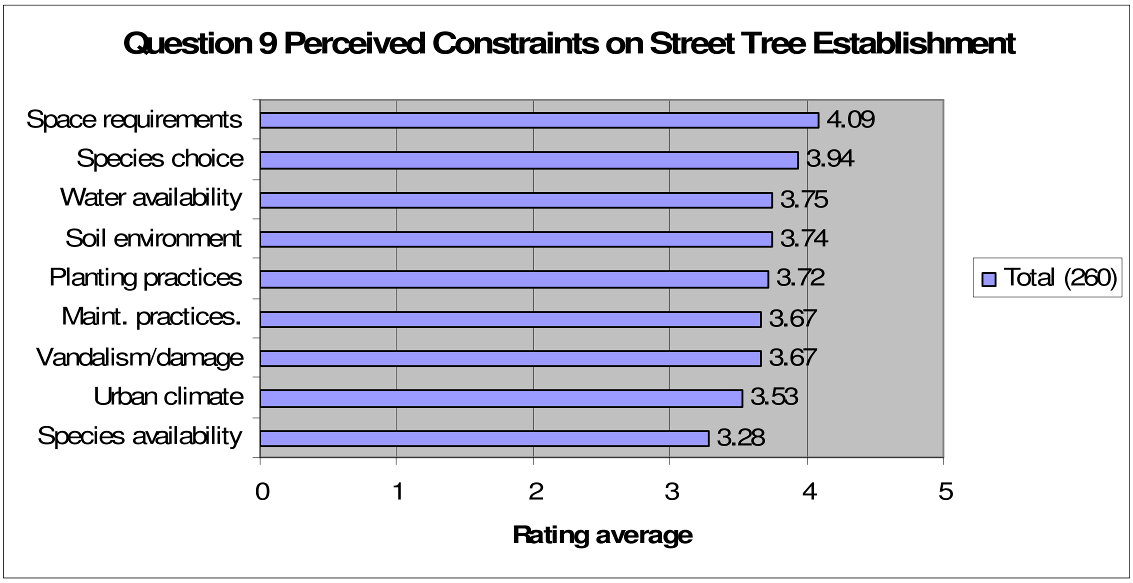

Figure 38: Perceived street tree constraints

How do you rate each of the following possible constraints on the successful establishment of trees in city streets, from least (1) to most (5)?							
Answer Options	**1**	**2**	**3**	**4**	**5**	**Rating Average**	**Response Count**
Space requirements	9	19	29	83	116	3.28	256
Soil environment	7	21	65	103	61	3.53	257
Harsh urban climate	7	31	83	90	46	3.67	257
Vandalism and damage	10	33	60	83	71	3.67	257
Planting and estab. practices	11	33	52	83	78	3.72	257
Maintenance practices	7	36	53	96	63	3.74	255
Water availability	9	33	51	83	77	3.74	253
Species choice	13	20	41	74	106	3.94	254
Species availability	22	48	65	69	47	4.09	251
Other (please specify below)							29
						answered question	**260**
						skipped question	**22**

Figure 39: Detailed responses: question 9

Discussion

A wide range of factors were considered to be constraints. Lack of space was rated as the main constraint. Limited species choice rated second. Both of these rated higher than water availability and a range of other physical constraints.

Open ended responses (28 responses)

It was noted that many street tree constraints can be overcome with appropriate species selection. Soils are a physical constraint in some areas. A wide range of organizational factors were also raised as constraints, including lack of knowledge, policies and support. Availability of appropriate tree stock was also identified as a constraint. Urban development and urban services were also identified as constraints.

Comparison of landscape architects and arborists.

Figure 40 presents responses of landscape architects (68) and arborists (98) to give an insight into any possible differences between the two disciplines in perceptions of constraints on street tree establishment. Both groups had a similar ranking of constraint factors, with the most important factor being space requirements. However arborists gave a consistently higher rating in all categories except space requirements, indicating that arborists perceive more constraints on tree establishment. One hypothesis may be that this is due to a greater knowledge by arborists of biological tree requirements and related constraints. Another may be the arborists more extended involvement with the tree life cycle and awareness of longer term failure due to poor planting practices.

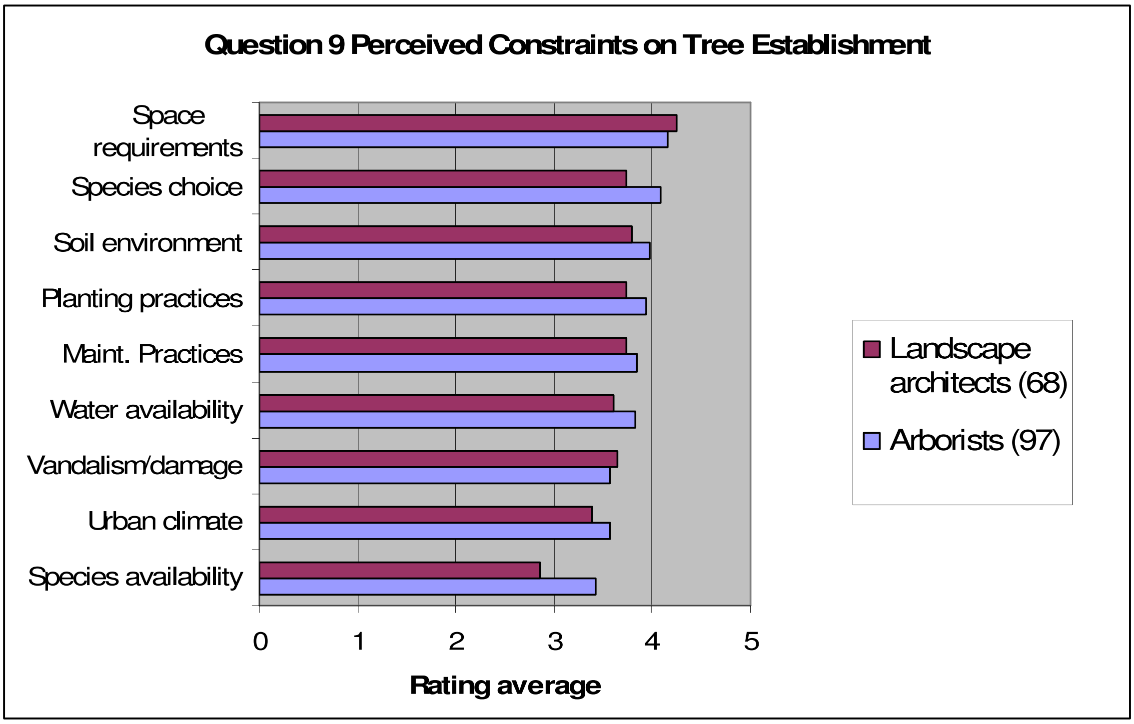

Figure 40: Perception of street tree constraints by landscape architects and arborists

Conclusion

The survey confirmed the findings of the literature review, that lack of space is the key constraint in urban street tree planting (Urban 1992). Lack of species choice also emerged as a significant factor, which was not highlighted in the literature review. Interestingly the issue of water availability was seen as of less significance than would be expected from the literature (Connellan 2008a).

10.3.4 Threats

Individual street trees, and the wider urban forest, are subject to a number of threats, both current and future. These include both direct physical threats, and the wider social and institutional context. Respondents were asked to rate the future threats to street tree planting, on a scale of 1-5. The intent of the question was to attempt to quantify respondent's perceptions of the threats to urban street trees, using categories identified in the literature review, and with provision for additional open ended comments. Figure 41 presents rating averages for all 253 respondents who answered the question. Figure 42 presents a more detailed analysis of responses to the question.

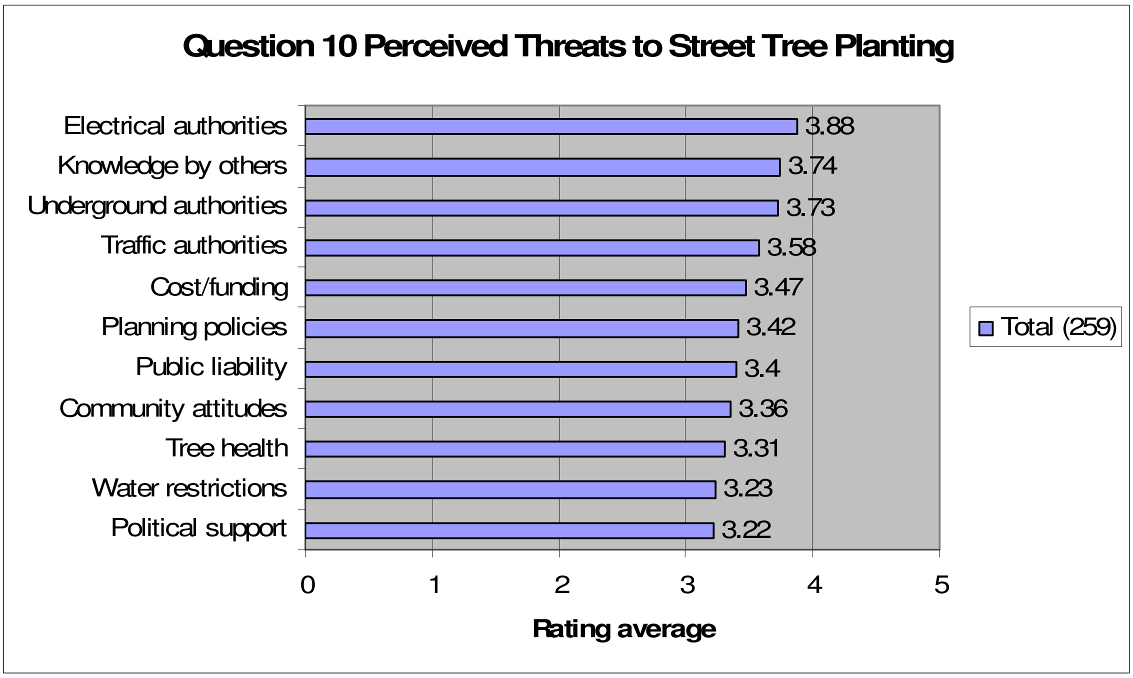

Figure 41: Perceived threats to street trees

How do you rate each of the following possible threats to street tree planting in your city, from least (1) to most (5)?							
Answer Options	**1**	**2**	**3**	**4**	**5**	**Rating Average**	**Response Count**
Electrical service authorities	7	27	53	74	97	3.22	258
Underground svc. authorities	6	33	56	89	72	3.23	256
Traffic authorities	5	38	65	99	49	3.31	256
Planning policies	14	42	71	78	50	3.36	255
Public liability	13	51	68	68	56	3.40	256
Cost/funding	13	40	71	77	55	3.42	256
Water restrictions	22	59	58	71	46	3.47	256
Community attitudes	20	45	63	78	50	3.58	256
Tree health	15	49	74	75	41	3.73	254
Lack of political support	29	52	58	67	50	3.74	256
Lack of knowledge by others	11	32	51	81	81	3.88	256
Other (please specify below)							21
						answered question	**259**
						skipped question	**23**

Figure 42: Detailed analysis of responses: question 10

Discussion

The main threats were identified as the policies of other authorities, especially electrical service authorities (and their tree pruning activities), and lack of arboricultural knowledge by others involved with street trees. Lack of political support, and water restrictions, were rated as the least severe threats.

Open ended responses (27 responses)

Service and other authorities were identified as external threats. Negative community attitudes were also identified as a significant threat. Other threat factors raised included water and climate.

Comparison of landscape architects and arborists.

Figure 43 presents responses of landscape architects (68) and arborists (98) to give an insight into any possible differences between the two disciplines in perceptions of future threats to street trees. Both groups had a similar ranking of threat factors; however the highest ranking for arborists was knowledge by others, which was given a lower priority by landscape architects. Arborists rated all threat categories higher than landscape architects, with the exception of the role of service authorities. This indicates that arborists may perceive more threats to trees due to their greater involvement in long term tree management.

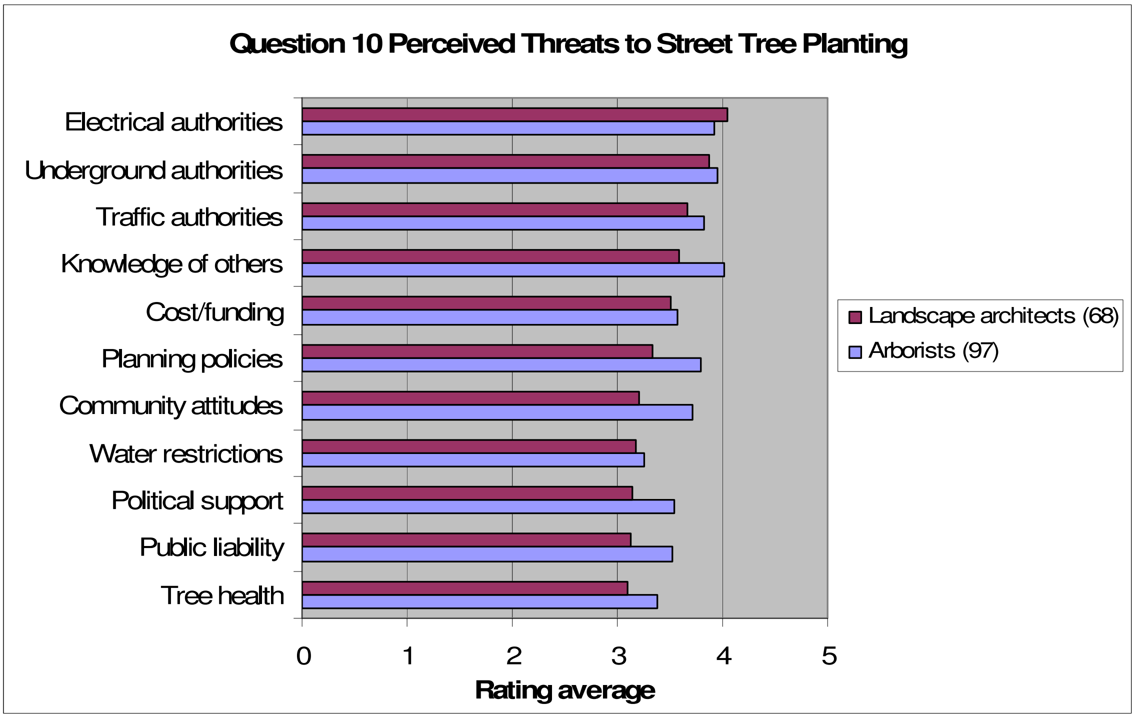

Figure 43: Perception of threats to street trees by landscape architects and arborists

Conclusion

The literature review identified a number of areas in which conflicts arose between street trees and urban infrastructure. This included hardscapes (Costello & Jones 2003), overhead services (Fakes 2000), underground services (Mattheck & Bethge 2000), buildings (Cameron *et al*. 2006) and traffic engineering requirements (Wolf & Bratton 2006). In each of these areas trees are given lesser status and priority than the engineering infrastructure. This reflects an area of conflict between arborists and engineers/asset managers. Solutions to such conflicts tend to be tree based, involving tree pruning, tree removal or restrictions on tree species or planting setbacks (Harris et al. 2004). The alternative would be an engineering based approach in which the infrastructure is designed to allow both trees and infrastructure to co-exist (Hitchmough (1994). The survey confirmed this in terms of an emphasis on the threats posed by the role of service and other authorities, especially electrical service authorities. The other significant perceived threat was lack of knowledge by others, which also emerged in the literature review in terms of the need for 'tree literate design' based on knowledge of the biological needs of trees (Coder1998). Interestingly water restrictions were not viewed as significant a threat as the above factors.

10.4 Uptake of practices

Questions 12-16 asked respondents about their uptake of a range of street tree related practices. Respondents were asked if they practiced, did not practice, or intended to practice. The following Figures present these data in the form of the percentage of respondents who reported that they did utilize a practice, for all respondents who answered that question. Provision was also made for open-ended responses, which are summarized in the text. A full tabulation of open-ended responses is also contained in Appendix A4. In the following sections the findings from each question are discussed and conclusions drawn.

It should be noted that these practice related questions provide a very simplified picture of the real world situation, necessitated by the need for brevity and simplicity in an online survey tool. The adoption of a practice may vary from widespread use, to occasional use, to use only in certain locations or situations. Similarly intention to adopt a practice can vary from a realistic short term intention to a long term ‘should do’ or ‘like to’. These issues are explored in greater depth in the following chapter 11.

10.4.1 Streetscape design

Appropriate streetscape design is seen as a key starting point to successful street tree planting and establishment. Respondents were asked if they currently practice, or intend to practice, a range of streetscape design practices. The intent of the question was to obtain a 'snapshot' of respondent's uptake of a number of streetscape design practices identified in the literature review, with provision for additional open ended comments. Figure 44 presents the percentage of respondents reporting that they do undertake certain practices (of all 234 respondents who answered the question). Figure 45 presents a more detailed analysis of responses to the question.

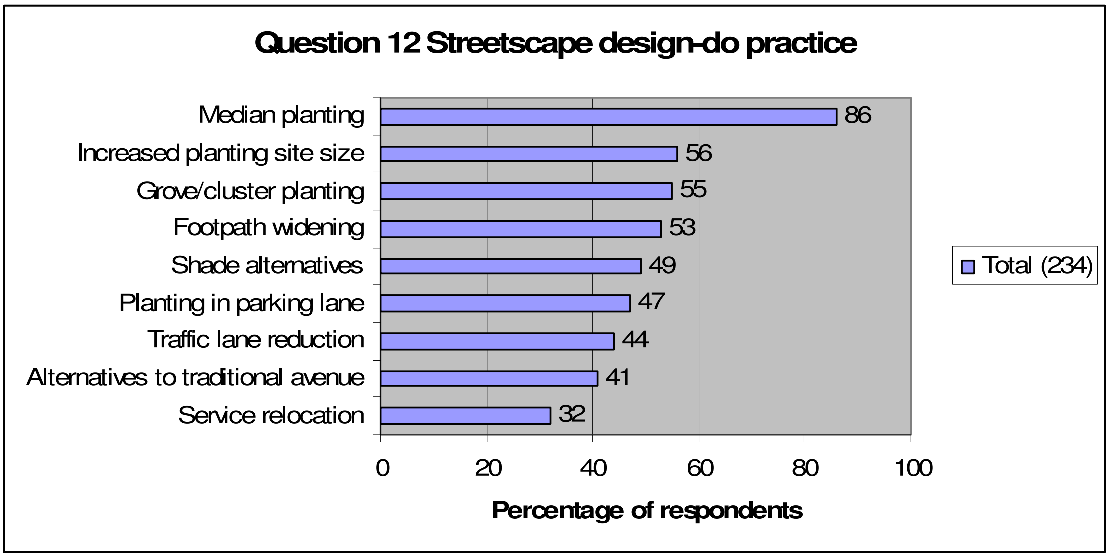

Figure 44: Rate of adoption of streetscape design practices

What is your Council's use of the following streetscape design practices?				
Answer Options	**Don't practice**	**Do practice**	**Intend to practice**	**Response Count**
Footpath widening	93	127	19	237
Traffic lane/width reduction	110	103	24	233
Service relocation to accommodate trees	136	75	29	237
Planting in parking lane	106	110	25	236
Median planting	29	204	6	237
Increased planting site size	74	132	36	234
Use of shade alternatives to trees	113	116	13	238
Grove or cluster planting	83	130	26	236
Alternatives to traditional avenue design	102	92	38	229
Other (please specify below)				30
			answered question	**239**
			skipped question	**43**

Figure 45: Detailed responses: question 12

Discussion

Median planting was the most common practice, with most Council's undertaking it in some form. This was followed by attempts to create more space for trees including larger planting sites, cluster planting and footpath widening. The least adopted practice was (costly) service relocation.

Open ended responses (30 responses)

Resistance to innovative practices, by engineers and others was mentioned. More stringent constraints on median planting were raised, as was the option of 'no trees'. Space available for tree planting varies. There can also be resistance to planting trees in the parking lane. Other streetscape design initiatives raised included aerial bundled cable and WSUD installations with street trees.

Conclusion

The literature review identified a number of strategies for the design of streets to better accommodate trees (Urban 2007). The survey showed that a number of these practices have already been adopted by some Councils, primarily increasing space for trees through measures such as footpath widening. Other desirable practices such as service relocations are less widely adopted, primarily due to cost factors.

10.4.2 Tree pit design

In recent years a better understanding has developed regarding the ‘landscape below ground’ and the need to address the design of the below-ground space to grow healthy, long lived trees. Respondents were asked if they currently undertake a range of tree pit design practices. The intent of the question was to obtain a ‘snapshot’ of respondent’s uptake of a number of tree pit design practices identified in the literature review, with provision for additional open ended comments. Figure presents the percentage of respondents reporting that they do undertake certain practices (of all 221 respondents who answered the question). Figure 47 presents a more detailed analysis of responses to the question.

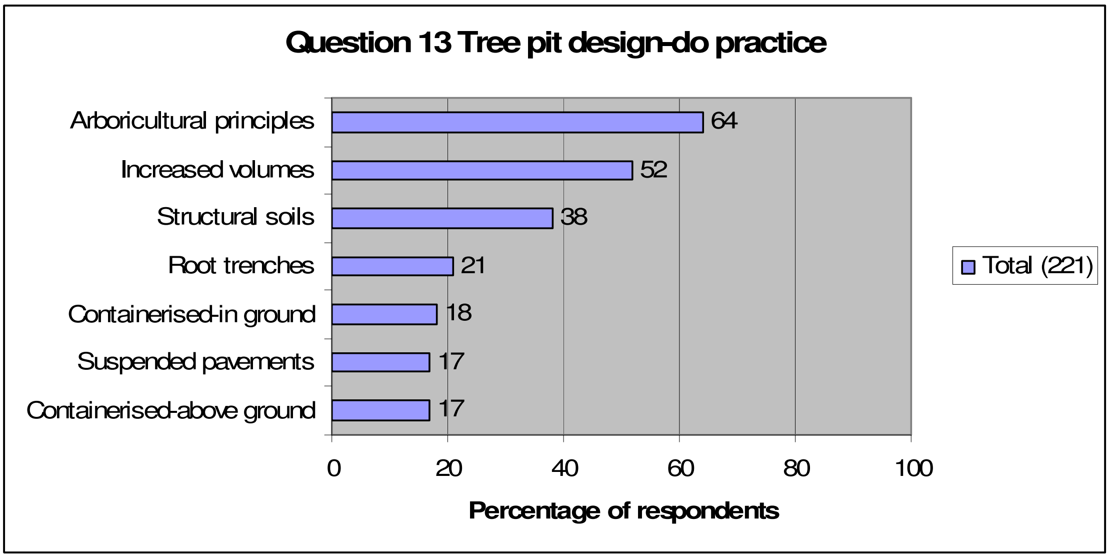

Figure 46: Rate of adoption of tree pit design practices

What is your Council's use of the following tree pit design practices?				
Answer Options	**Don't practice**	**Do practice**	**Intend to practice**	**Response Count**
Increased tree pit volumes	82	118	34	226
Design based on arboricultural principles	57	144	30	224
Continuous tree root trenches	141	48	40	223
Structural soils	105	84	40	221
Suspended pavements	152	39	33	222
Containerized trees-above ground	172	41	13	223
Containerized trees-in ground	171	41	9	221
Other (please specify below)				37
			answered question	**226**
			skipped question	**56**

Figure 47: Detailed responses: question 13

Discussion

The most widely adopted practices were the design of the below ground space on arboricultural principles, including increased soil volumes. There was also a higher uptake of structural soils than other innovations such as root trenches and suspended pavements.

Open ended responses (35 responses)

A number of respondents mentioned a low uptake of improved practices, despite their desirability. Innovations such as structural soils and root trenches are used only occasionally. Root barriers were also mentioned as a below ground practice.

Conclusion

The literature review identified the need for increased rootable soil volumes as a key to growing healthy, long lived street trees (Craul & Craul 2006). It also identified a wide range of below ground technical innovations aimed at increasing soil volumes in the urban landscape (Thompson & Sorvig 2008). However it also recognized the need, first of all, to get the basics of tree planting and establishment correct (Harris *et al*. 2004). The survey confirmed this emphasis on adopting sound arboricultural practices. More technical below ground innovations, although highlighted in the literature, have been less widely adopted, although there is an expressed interest in pursuing innovative practices such as structural soils and rot trenches, in appropriate situations.

10.4.3 Infrastructure design

Conflicts with surrounding urban infrastructure are a key consideration in urban tree planting, but practices to reduce conflicts are often engineering-driven and of detriment to trees. Respondents were asked if they currently undertake a range of infrastructure design practices. The intent of the question was to obtain a 'snapshot' of respondent's uptake of a number of infrastructure design practices identified in the literature review, with provision for additional open ended comments. Figure 48 presents the percentage of respondents reporting that they do undertake certain practices (of all 226 respondents who answered the question). Figure 49 presents a more detailed analysis of responses to the question.

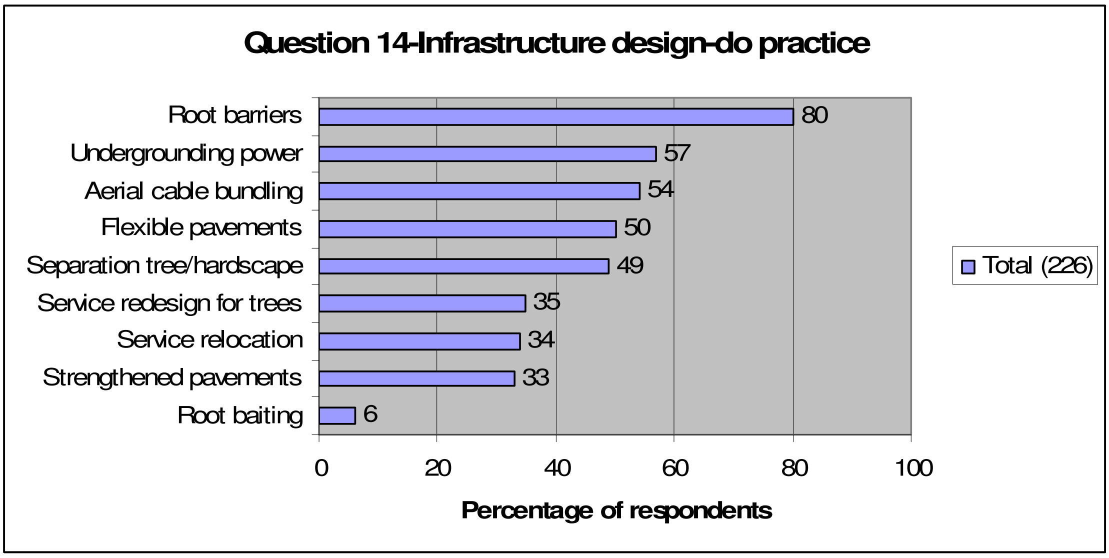

Figure 48: Rate of adoption of infrastructure design practices

What is your Council's use of the following infrastructure design practices?				
Answer Options	**Don't practice**	**Do practice**	**Intend to practice**	**Response Count**
Separation of tree/hardscape	101	108	13	219
Root barriers	40	181	8	226
Root baiting	197	15	10	221
Strengthened pavements	134	75	18	223
Flexible pavements	87	117	27	228
Relocation of services	124	78	27	227
Undergrounding of power	71	131	29	228
Redesign of services to accommodate trees	114	86	33	228
Aerial cable bundling	82	118	25	220
Other (please describe below)				32
			answered question	**231**
			skipped question	**51**

Figure **49: Survey data question 14**

Discussion

Root barriers appear to be an almost universal practice, and the main strategy to reduce infrastructure conflicts, despite qualifications about their value. Other popular service related practices include undergrounding power, and aerial bundled cabling, both of which reduce tree pruning impacts. Popular hardscape practices include the use of more flexible pavements, and increased separation between trees and hardscape. Less popular were costly service relocations, and stronger pavements (which may have a detrimental effect on trees). The least adopted practice was root baiting (control of tree root growth by soil water management) due either to its difficulty, or lack of awareness of the term by respondents.

Open ended responses (32 responses)

Once again improved practices may be limited in uptake, despite their desirability. Undergrounding of power may be limited by cost. In some areas aerial bundled cabling is the responsibility of service authorities rather than Council. The cost of service redesign or relocation may also be prohibitive.

Conclusion

The survey confirmed a finding of the literature review, that root barriers are the main tool for dealing with tree/infrastructure conflicts, despite uncertainties as to their effectiveness (Gilman 2006). Undergrounding of power and aerial bundled cabling are also widely adopted practices (Fakes 2000). In terms of hardscapes, the main emphasis apart from root barriers is on more flexible pavements (Costello & Jones 2003) and increased tree/hardscape separation (Gilman 1997). Service resign or relocation, although desirable, is not widely adopted, due to costs.

10.4.4 Water management

Providing the appropriate conditions for growth, especially an adequate water supply, is a key consideration in street tree planting and management, which is likely to be exacerbated in the future due to drought and climate and change. Respondents were asked if they currently undertake a range of water management practices. The intent of the question was to obtain a 'snapshot' of respondent's uptake of a number of water management practices identified in the literature review, with provision for additional open ended comments. Figure 50 presents the percentage of respondents reporting that they do undertake certain practices (of all 226 respondents who answered the question). Figure 51 presents a more detailed analysis of responses to the question.

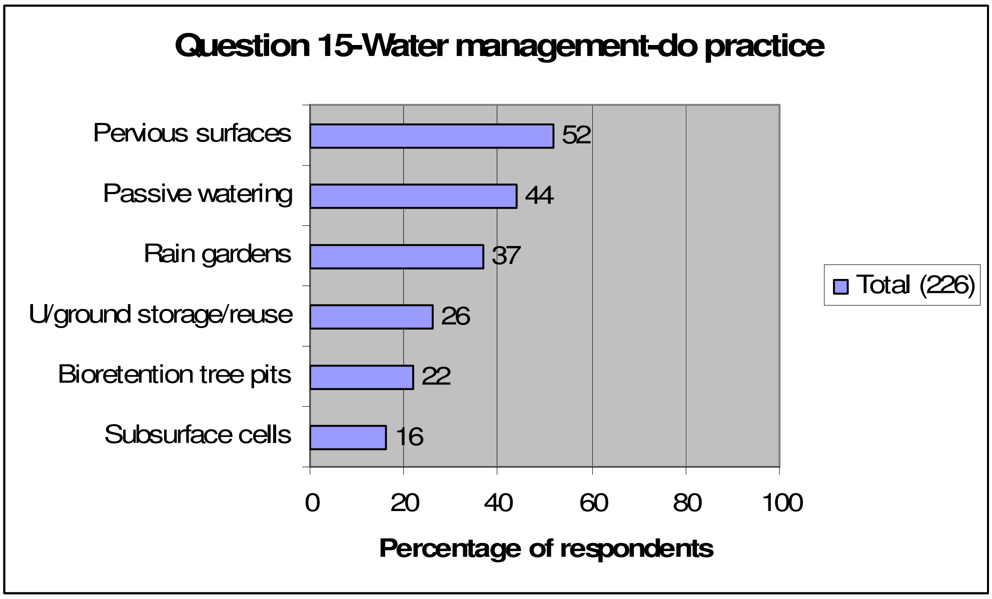

Figure 50: Rate of adoption of water management practices

What is your Council's use of the following street tree water management practices?				
Answer Options	**Don't practice**	**Do practice**	**Intend to practice**	**Response Count**
Increased pervious surfaces	82	121	36	231
Passive watering with stormwater runoff	91	101	44	230
Rain gardens/bioretention basins	111	84	35	228
Bioretention tree pits	126	50	53	225
Underground storage and reuse	128	57	46	225
Subsurface "cells"	145	36	48	224
Other (please specify below)				34
			answered question	**231**
			skipped question	**51**

Figure 51: Detailed responses: question 15

Discussion

Use of pervious surfaces was the most widely adopted practice. This was followed by the use of stormwater for passive irrigation and raingardens. Other WSUD practices are less well adopted, and are still in the process of widespread acceptance as best practice.

Open ended responses (33 responses)

The extent of adoption of WSUD practices is also limited to occasional or experimental use. In some areas WSUD may be the responsibility of subdivision developers, with Council possibly imposing conditions on approvals. Several respondents have been using recycled water on street trees and parks.

Conclusion

The literature review identified water management as a key strategy for a sustainable urban forest, especially in times of drought, water restrictions and climate change (Connellan 2008a). Water Sensitive Urban Design was also identified as an emerging strategy with direct and indirect benefits to urban trees (Day & Dickson 2008). The survey identified a relatively low uptake of WSUD practices, but interest in adopting innovations such as bioretention systems (Breen *et al*. 2004). The main practices adopted are the less 'technical' ones of porous surfaces (Ferguson 2005) and passive watering with stormwater runoff (Lawry 2008).

10.4.5 Tree species selection

Selecting the 'right tree for the right place' is considered to be key strategy to address a range of street tree related issues, such as available space, potential infrastructure conflicts and climatic suitability. Respondents were asked if they currently undertake a range of street tree species selection practices. The intent of the question was to obtain a 'snapshot' of respondent's adoption of different tree species practices or criteria identified in the literature review, with provision for additional open ended comments. Figure 52 presents the percentage of respondents reporting that they do undertake certain practices, (of all 227 respondents who answered the question). Figure 53 presents a more detailed analysis of responses to the question.

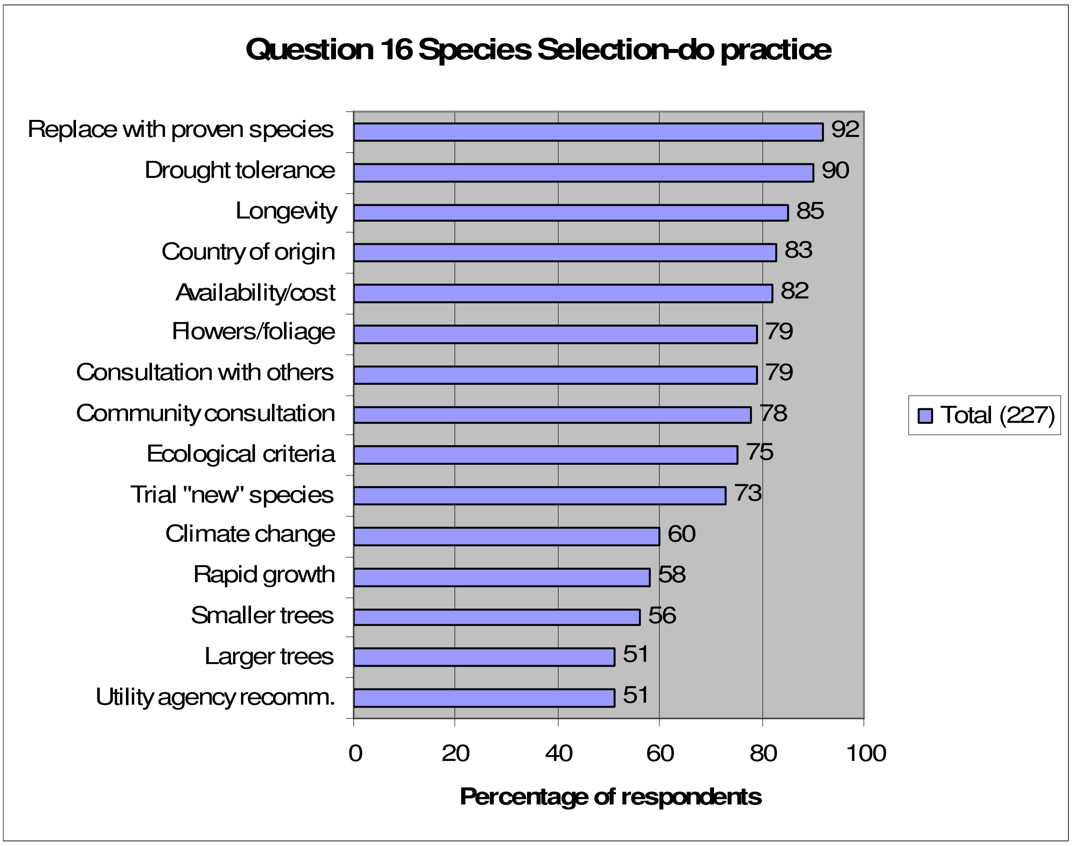

Figure 52: Rate of adoption of tree species selection practices-

What is your Council's use of the following tree species selection practices/criteria?				
Answer Options	**Don't practice**	**Do practice**	**Intend to practice**	**Response Count**
Location/country of origin	35	191	4	230
Plant fewer larger trees	107	116	6	226
Plant more smaller trees	96	127	8	227
Availability and cost	42	185	1	227
Attractive flowers or foliage	46	181	4	229
Rapid growth	93	134	2	228
Longevity	28	197	7	230
Changing climate	69	137	25	228
Ecological criteria	45	171	12	228
Drought tolerance	13	205	13	228
Consultation with community	40	179	12	227
Consultation with landscape architects/others	38	180	10	227
Replace with existing proven species	14	208	5	225
Opportunity to trial "new" species	41	165	26	227
Recommendations by utility agencies	103	113	8	222
Other (please specify below)				31
			answered question	**232**
			skipped question	**50**

Figure 53: Detailed responses: question 16

Discussion

Tree species selection still appears to be the main tool for arborists to improve street tree practices. The most highly rated selection criteria are the practical ones of replacing trees with proven species, and selecting for drought tolerance in existing and future conditions of drought and water restrictions. The least favoured practice was adopting utility agency recommendations.

Open ended responses (31 responses)

Some respondents promote the use of local or indigenous planting. Tree size is dependent on location. Consultation may be undertaken with others, but the recommendations of arborists are considered preferable to those of service authorities.

Conclusion

Tree species selection was not addressed as a separate topic in the literature review, but rather it emerged as a significant consideration or potential strategy in a number of areas (Harris *et al.* 2004). The survey identified a strong preference for planting proven species, and selecting for drought tolerance and longevity. There was little support for selecting trees on the basis of utility agency recommendations. Interestingly climate change was as significant a factor as expected.

Additional survey comments (51 responses)

Respondents were invited to provide any additional comments. Comments focussed on Council organizational and management factors, rather than physical considerations. These included negative community attitudes to trees and the need for benefit education. Some respondents promoted the need for an urban forestry approach to street tree management. Some Council's have prepared detailed street tree strategies. Physical factors raised included lack of planting space in urban development, water restrictions and tree species selection including drought tolerance and the need for an 'ideal' street tree.

10.5 Conclusion

A quantitative study was undertaken to obtain a 'snapshot' of the attitudes and practices of local government street tree managers throughout Australia. A web based survey was developed using the services of an online service provider, with an online link distributed to local government arborists and landscape architects, and also to local government planners, engineers and asset managers. 261 respondents completed the survey, from all Australian states, representing 109 Councils and related bodies. Approximately half of respondents were arborists/ horticulturists, and one quarter landscape architects. The survey explored the attitudes and perceptions of respondents in terms of street tree benefits, street tree issues, constraints on street tree planting, and future threats to urban trees. Uptake of a range of practices was also explored, including streetscape design, design below ground, infrastructure design, water management and tree species selection. Survey results were presented in tables and simple graphic form. While the survey provided a valuable 'big picture', methodological constraints did not allow for a detailed understanding of many issues. The survey was therefore followed up with in depth interviews to gain a deeper understanding of the topics addressed in the survey (Refer to Chapter 11).

A number of final conclusions have been drawn from the survey results.

- There is a high level of recognition of the benefits of street trees, including their environmental benefits. But the highest rating was given to the more intangible and less widely researched visual and aesthetic benefits of street trees.

- The key street tree issue was infrastructure damage, followed by tree health/longevity and liability/risk.

- The main constraint on street tree planting is lack of space, followed by lack of species choice.

- The key threat to future street tree planting was seen to be the role of various external authorities, especially electrical service authorities, but also including other service providers and road traffic authorities. Lack of knowledge by others was also seen as a significant threat. However water availability was not perceived as such a significant threat.

- The main streetscape design practices adopted comprises increasing planting site sizes, through strategies such as footpath widening.

- The main approach to tree pit design comprised design based on sound arboricultural principles, and increasing soil volumes where possible. There is limited uptake of technical innovations such as structural soils.

- The key strategy for managing tree/infrastructure conflicts remains the root barrier. Undergrounding of power and aerial bundled cable are also widely adopted, however strategies such as service relocations to accommodate trees appear to be prohibitive in most cases. With respect to hardscapes, the main strategies are more flexible pavements and increased tree/hardscape separation.

- There has been limited adoption of recent WSUD innovations, but interest in adopting practices such as bioretention tree pits. The main practices adopted comprise porous surfaces and passive watering with stormwater runoff.

- Tree species selection practices emphasize maintaining a sustainable urban forest, and include planting of proven species, and long lived, drought tolerant species. There is little support for planting based on utility authority recommendations.

- Both landscape architects and arborists recognize the benefits of street trees. However there are differences in attitudes and perceptions in areas such as street tree issues and threats, likely due to arborists longer term involvement with the tree beyond the initial planting phase.

11 Metropolitan Adelaide Study

11.1 Introduction

In 2009 a study was undertaken of the attitudes and practices of local government tree managers in the Adelaide metropolitan region. The study adopted a qualitative research strategy using an in-depth interview methodology. The study had two main aims: to provide a profile of attitudes and practices for the specific study area; and to explore 'in-depth' the topics addressed in the foregoing quantitative method national online survey.

11.2 Methodology

Ethical issues

Qualitative studies often raise a range of ethical and personal issues, as the researcher may be involved in a close personal interaction with participants, and will play an active role in interpreting the research findings (Creswell 2009). Researchers need to explicitly identify their biases, values and personal background which may influence their interpretations in a quantitative study. Researchers also need to comment on any connections between study participants and their work sites (Glesne & Peshkin 1992). Steps to access to participants and to interview settings should be identified (Marshall & Rossman 2006). Steps taken to mask information to ensure anonymity should also be identified

In this study the researcher is a landscape architect with a 'pro-tree' and 'sustainable design' bias, which is one of the explicit values of that profession. He has not been employed by any of the organizations interviewed in the study, and had previously met several of the interviewees.

Participants were contacted by phone or email to arrange an interview, with interviews taking place at the participant's workplace. All of those approached consented to be interviewed, and supported the study objectives as being of value to their professional work. The only constraint was interviewee time and availability, with all participants being in senior positions in the organization.

Ethics approval was obtained from the University Ethics Board. Participants were forwarded an information sheet and consent form (to be signed), prior to the interview (Refer Appendix B1 and B2). Participants were advised that the interview results would remain anonymous and confidential, and that they would be given an opportunity to view and comment on their record of interview. Interviews were taped and transcribed by the researcher, and all interview documents held confidentially by the researcher. To 'mask' information obtained, each interviewee was given an identification code number, in place of a name, for identification purposes, to ensure the anonymity of the interviewee and their organization, in the study write up. Participants were forwarded a copy of the full interview transcript for review and given the opportunity to make any additions or amendments to the text if necessary.

Participants indicated that ethical issues were not generally an issue in the study, which was primarily concerned with street tree issues. However anonymity and confidentially were of value in allowing the participants to openly comment on the attitudes of other Council staff, elected members and ratepayers.

Selection of participants

It is important to note that

> *The idea behind qualitative research is to purposely select participants or sites (or documents or visual material) that will best help the researcher understand the problem and the research question. This does not necessarily suggest random sampling or the selection of a large number of participants or sites, as typically found in quantitative research* (Creswell 2009 p.178).

The metropolitan Adelaide region was adopted as the study area, which comprises a statutory grouping of eighteen local government organizations. The Adelaide Hills District Council and the District Council of Mount Barker were also included in the interviews. While not officially part of the Adelaide metropolitan region, they comprise one of the main growth areas of greater Adelaide (Department of the Planning and Local Government 2009). Interviews were conducted with the Adelaide City Council (ACC), but these have not been included in the analysis as the ACC comprises a distinctly different tree planting situation to the other metropolitan Councils. The intention of the research was two-fold: to provide a useful 'case-study' of attitudes and practices within the defined region; and to provide in-depth meaning to the findings of the quantitative national practitioner study. Table 59 summarizes the local government organizations interviewed and included in the data analysis. For the purpose of analysis, Councils were also broadly categorized into eastern, western and outer urban sub-regions, each having broadly similar physical settings and patterns of urban development (Department of the Planning and Local Government 2009).

Table 59: Organizations interviewed

Council		
Eastern urban	**Western urban**	**Outer urban**
Adelaide Hills	Charles Sturt	Gawler
Burnside	Holdfast Bay	Mount Barker
Campbelltown	Marion	Onkaparinga
Mitcham	Port Adelaide Enfield	Playford
Norwood, Payneham and St Peters	Prospect	Salisbury
Unley	West Torrens	Tea Tree Gully
Walkerville		

The senior tree manager in each local government area was identified for interview. As the organizational structure of each organization varies, this was either an arborist, landscape architect or asset manager (Refer Table 60). In some organizations a second interview was undertaken with another staff member as recommended by the first interview participant. Most interviews were undertaken between 17 September 2009 and 17 December 2009.

Table 60: Position of interviewee in organization

Participant's position	Number
Arborist, horticulturist, tree manager	6
Parks, gardens, open space manager	4
Landscape architect, urban designer	4
Operations, infrastructure manager	3
Natural resource manager	2

Interviews were conducted in a room at the participant's workplace. Open-ended, face-to-face interviews are considered to be a useful method in qualitative research for developing an understanding of the holistic qualities of real world situations, which may be oversimplified in quantitative survey research (Groat & Wang 2002). Limitations include: the fact that information is filtered through the views of the participant; possible response bias due to the presence of the researcher; and not all participants are equally perceptive or articulate (Creswell 2009). Interviews also create practical issues including the time involved in conducting and transcribing interviews, and dealing with very large quantities of textual data (Groat & Wang 2002).

Data collection procedures

Face-to-face interviews were conducted, using a fixed set of questions but with open ended responses by participants. Interviews were taped, after gaining the participants approval, and notes also taken in the event of recording equipment failure.

An interview protocol was developed listing the questions to be asked (Refer Appendix B3). The information sheet, consent form and copy of the protocol were provided to the participant prior to the interview. However the participant was not requested to pre-prepare any information for the interview or to supply any relevant documents. The following questions were included in the protocol and were asked in the following order.

Opening remarks.
Part A Council context.
A1 What is your role in Council?
A2 What is the role of street tree planting in your Council area?
A3 What is the level of support for urban tree planting at the strategic level?
A4 Do you operate under a wider street tree planting strategy or master plan?
A5 What are the interactions between different disciplines within Council?
Part B Issues.
B1 What do you see as the main benefits of street trees?
B2 What do you see as the main issues or problems associated with street trees in your area?
B3 What do you see as the main constraints to successful tree planting and establishment?
B4 What do you see as the main threats to the future of street trees in urban areas?
Part C Practices.
C1 What practices have you adopted, or intended to adopt, to grow healthier trees in urban streets, or to reduce tree/infrastructure conflicts?
C2 What practices do you consider to be the most viable to grow healthier trees in urban streets, or to reduce tree/infrastructure conflicts?
C3 What factors do you consider prevent or limit the adoption of these practices?
Closing remarks

Data analysis procedures

The process of data analysis and interpretation involved a systematic process of 'making sense' of a large amount of textual data. Analytical themes 'emerge' from the data, rather than from pre-conceived categories the researcher brings to the study. According to Creswell (2004 p.184)

> *Data analysis involves collecting open-ended data, based on asking general questions and developing an analysis from the information supplied by participants.*

Data were first prepared for analysis by transcribing the record of interview as verbatim text. Data were then coded. Coding is the process of segmenting 'chunks or segments' of text into different categories (Tesch 1990; Rossman & Rallis 1998). Categories are then be labeled with a term, which can be based on the actual label used by participants (an *in vivo* term) (Creswell 2009).

Computer programs can be used to provide an efficient method of storing, coding and analyzing data. In this study text was coded and analyzed using *QSR NVivo* software (http://www.qsrinternational.com/default.aspx). While it is still necessary to develop codes, and assign a code to every segment of text, the process is much quicker than hand coding, and a large data base can be developed in which segments of text can be quickly accessed and compared. The software also provides for the development of 'analysis frameworks' with hierarchies of categories used during the analysis, and the ability to 'query' or interrogate the database, and compare information related to specific respondents or analytical categories. The original coded text is included in Appendix B4.

The software based coding process was then used to identify a number of emerging themes. Themes and more detailed sub-categories were then presented in a qualitative narrative form supported by verbatim quotations. Quotations are used both to: support common themes; and to display multiple perspectives of participants (Creswell 2009). The narrative attempts to convey the key findings which have emerged from the analysis of a large volume of textual data, and includes detailed discussion of themes, supported by quotations. It is also supported by the more visual presentation of data summarized in comparative tables.

The final step, interpretation of the data, involves comparing the findings with information from other sources including the literature review and quantities research data, suggesting how the data confirm or diverges from other findings (Creswell 2009).

Reliability and validity considerations

Concepts of reliability and validity in qualitative studies differ from those in quantitative research, (where reliability means internal consistency of responses, and external validity the ability to generalize sample results to a wider population) (Creswell 2009).

In qualitative research reliability indicates that the researcher's approach is consistent across different researchers or settings (Creswell 2009). Gibbs suggests a number of reliability procedures including: checking transcripts for obvious mistakes; and making sure there is no 'drift' in coding definitions by constantly comparing data with codes during the coding process. Additional requirements will also need to be met if more than one researcher is involved, which was not the case in this study (Gibbs 2007). Researchers also need to establish detailed procedures and protocols, and document in detail every step in the actual procedures followed (Yin 2003). In this study only one researcher was involved, and a standardized set of questions and procedures was documented in detail and applied consistently at each interview. Data were coded and analyzed using coding software that allowed efficient comparison of data from different interviewees.

The concept of external validity, or ability to generalize, is used in a limited way in qualitative research, since the intent is often not to generalize to populations or sites outside those under study. Particularity rather than generalizability is one of the hallmarks of qualitative research (Gibbs 2007). Yin however considers that qualitative case studies can be generalized to broader theory (Yin 2003). Creswell consider validity to be one of the strengths of qualitative research, if the findings are accurate from the viewpoint of the researcher, the participants and readers of the account (Creswell 2009). Validity strategies are much discussed and multiple strategies are recommended (Creswell & Miller 2000). The following validity strategies were adopted in this study: triangulation from a number of data sources to establish themes; member checking to determine accuracy including the review of transcripts, and review by interviewees of a preliminary write up of the study findings; use of a narrative including rich text quotations, to give the reader the sense of a shared experience; clarifying any researcher bias; and inclusion of negative or divergent views running counter to established themes (the existence of divergent views gives a more valid ‘real world’ perspective).

11.3 Study findings

11.3.1 Introduction

The following sections provide a narrative summary of participant responses to key questions, illustrated with verbatim quotations. Each quotation has a label identifying the participants sub-region: (E) eastern, (W) western, or (O) outer urban. However the identity of the specific respondent remains anonymous. A matrix is also presented for each key question, summarizing the main themes, categories and sub-categories that emerged in the data analysis phase. As data were analyzed, it became evident that response could be categorized into three main themes: physical or design factors; human factors; organizational factors. A more detailed table is also presented for each question, summarizing interview responses classified by respondent location. Responses are coded into categories which emerged from the interview data.

11.3.2 Street tree benefits

Question: What do you see as the main benefits of street trees?

Table 61 provides a summary of the main street tree benefits which emerged as consistent themes from the analysis of interview data. Table 62 comprises a more detailed analysis of perceived benefits classified by respondent location.

Table 61: Summary of perceived street tree benefits

Themes	Categories	Sub-categories
Visual, aesthetic		
Character and amenity	Visual character	
	Streetscape appeal	
	Suburb desirability	
	Resident support	
Identity	Legibility	
Environmental		
Climatic-shade	Amenity	
	Environmental	Urban heat island
		Climate change
		Pavement life
Atmospheric	Air quality	
Water	Runoff	
	Quality	
Ecological	Biodiversity, corridors	
	Location factors	
Other	Soils, glare	
Economic		
Real estate values		
Ecological services		
Social		
Human well-being	Quantifiable	
Cultural	Heritage	
Source: Compiled from participant interviews.		

'The usual list of environmental benefits is ok-but more often than not you notice when you drive down a street that has been upgraded. If you get good street trees you get good aesthetic appeal. ' E - 2

'Tree planting is a relatively cheap way of improving the amenity and character of an area. Trees provide shade. They soften the line of the road and infrastructure, and create light and shade.' E2

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

> *'When a person drives down the street, the biggest impact is the tree. And the leafiest suburbs, that's why the value of the houses are higher than elsewhere, because it's usually the leafy streets, or leafy suburbs.' O1*

In developing outer suburban areas street tree planting also plays a significant role in creating local character and identity.

There is a long list of environmental benefits including impacts on urban climate, air quality and stormwater management. However the most frequently mentioned factor is shade, with its multiple benefits for pedestrians, vehicles, and the urban heat island effect. According to one participant,

> *"Number one is shade, and obviously you can go on about that forever.' O5*

The ecological benefits of street trees were less emphasized and depend more on location, being of greater significance as biodiversity corridors in outer urban areas. Perceived economic benefits relate mainly to property values. There is an awareness of the relationship between urban greening and human well-being; however this is less tangible and more difficult to communicate to the public than the more obvious visual benefits. In the words of one participant,

> *'The most important benefit, they maintain quality of life and community. A lot of people don't see that.' E4*

Table 62: Perceived street tree benefits by respondent location

	Respondent																		
	Eastern							**Western**						**Outer**					
Response categories	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**1**	**2**	**3**	**4**	**5**	**6**	**1**	**2**	**3**	**4**	**5**	**6**
Extensive	x	x			x		x		x			x	x	x			x	x	
Character/ amenity																			
Amenity	x	x	x					x		x			x			x			x
Visual		x			x		x					x			x				
Desirability			x		x		x							x				x	
Streetscape appeal		x			x						x			x					
Identity										x					x	x	x	x	x
Support						x	x										x		
Economic																			
General				x		x													x
Property		x	x				x			x				x					x
Ecological services				x															
Environmental																			
General	x		x		x	x	x				x	x		x					
Climatic																			
Shade																			
-Amenity	x	x		x				x					x		x		x	x	
-Urban Heat Island			x					x	x	x			x			x			
-Climate change								x	x								x		
-Pavement life								x										x	
Glare								x											
Atmospheric																			
Air quality	x			x				x		x	x		x						
Water																			
Runoff				x				x		x		x							
Quality																			
Soils								x											
Ecological																			
General								x			x		x		x	x	x	x	
Social																			
Well being				x	x							x							x
Quantified				x															
Cultural	x				x														
Other																			
Big tree benefit																		x	
	1	**2**	**3**	**4**	**5**	**6**	**7**	**1**	**2**	**3**	**4**	**5**	**6**	**1**	**2**	**3**	**4**	**5**	**6**

11.3.3 Street tree issues.

Question: What do you see as the main issues or problems associated with street trees?

Table 63 provides a summary of the main street tree issues which emerged as consistent themes from the analysis of interview data. Table 64 comprises a more detailed analysis of perceived issues classified by respondent location.

Table 63: Summary of perceived street tree issues

Themes	Categories	Sub-categories
Physical		
Urban development	Urban infill	Implications
		Compensation
	New subdivisions	
Lack of space	Verge widths	
	Authority constraints	
Infrastructure	General	Infrastructure damage
		Tree damage
	Hardscape conflicts	Liability
	Service conflicts	ETSA pruning
		Private services
Water	Restrictions	Drought, climate change
	Loss of alternative sources	
	Mature tree impacts	
Tree species selection	Past decisions	
	Selection criteria	
Human		
Resident attitudes	Nuisance, litter	Ageing population
	Property damage	Liability
	Vandalism	Illegal removals
	Lack of benefit awareness	
	Overprotective attitudes	
Organizational		
Attitudes	Engineers, planners	
	Change resistance	
Implementation	Resources	
Source: compiled from participant interviews.		

'The other problem I have, this will sound strange, is the residents. Residents like trees, but they seem to have a passion for disliking the tree that's in front of their house. Because things drop leaves you see. And every tree has got problem, or a fault, or a branch that's fallen, or something like that. And it always seems to be the tree in front of their house, never the neighbour's tree. And trying to keep them happy.' E7

There are a number of street tree issues that must be dealt with by urban tree managers. The major issue emphasized is the human dimension of negative community attitudes to street trees. Residents are thought to be less tolerant of nuisance factors, especially leaf litter, and this can be linked to the ageing of the population, with older residents less tolerant of ‘mess’, and their ability to deal with it. Related factors include perceived property damage and associated liability issues.

> *'If you look at the complaints coming through the city here, it’s that older generation that are house proud, and tidying up the trees mess has got beyond them.' O4*

Other key issues include tree-infrastructure conflicts, especially with hardscape and underground services, exacerbated in areas with narrow verges and constraints on space. According to one inner suburban participant,

> *'Probably the main area is the conflicts with infrastructure. We’re very tight, we’re inner suburban, we’re dealing with narrow footpaths in the context of people who want a canopy tree. And it’s not always possible.' E6*

And an outer suburban Council:

> *'The lack of physical space to plant trees, particularly in the verges is probably the biggest issue.' O2*

ETSA pruning practices are a major concern, especially in bushfire prone areas.

> *'ETSA are a problem and they have always been a problem. Their disregard of correct pruning techniques, hiding behind the claim they must provide power to customers, at the expense of street trees, is false and irresponsible.' W5*

Water availability is also an issue, in terms of the impacts of water restrictions, drought and climate change.

> *'I’ve found the biggest strain with the tree network, over the last 8 years, has been the climatic conditions. It’s had a hell of an impact on streetscapes.' W6*

Water restrictions have impacted on mature trees as well as tree establishment practices, seen partly as a consequence of past inappropriate (but unforeseen) species selection. A particular concern for street trees has been the loss of a supplementary water source from suburban front gardens.

> *'People used to water nature strips, and the grass areas their side of the fence. I think that moisture in a lot of instances got to the trees. Well that’s been excluded from the equation and the trees are suffering.' W6*

Table 64: Perceived street tree issues by respondent location

Response categories	Respondent																		
	Eastern suburbs							Western suburbs						Outer suburbs					
	1	2	3	4	5	6	7	1	2	3	4	5	6	1	2	3	4	5	6
General			x	x							x								x
Urban development																			
Urban infill			x		x			x						x					
-Implications		x																	
New development																			x
-tree establishment															x				x
Space																			
Verge width															x	x			
Constraints	x					x	x			x	x		x						
Infrastructure conflicts																			
Infrastructure damage							x		x				x						
Tree damage							x				x								
Hardscape																			
Damage								x							x				
Liability									x										
Services																			
Issues													x		x	x			
ETSA pruning	x				x							x		x				x	
Private services																	x		
Water																			
Impacts						x					x		x	x		x			
Sources						x					x			x	x				
Mature trees												x	x			x			
Practices adopted						x						x				x			
Species selection																			
General	x	x								x									
Past decisions					x												x	x	
Drought		x																	
Limited choice								x		x									
Perfect tree								x		x									
Natives										x									x
Risk						x													
Longevity																		x	
Resident attitudes											x								
Succession planning	x													x					
Human factors																			
Anti tree attitudes										x			x						
-Litter			x	x	x		x								x		x		
-Ageing population													x				x		
Vandalism											x	x		x					
Property damage			x	x				x						x	x				
Liability	x				x		x		x						x				
Traffic accidents																	x		
Unaware of benefits				x			x												
Protective attitudes		x				x													
Organizational																			
Resources														x		x			
Planner attitudes														x					
Engineer attitudes														x					x
Change resistance							x												
	1	2	3	4	5	6	7	1	2	3	4	5	6	1	2	3	4	5	6

11.3.4 Constraints on street tree planting

Question: What do you see as the main constraints to successful street tree planting and establishment?

Table 65 provides a summary of the main constraints on street tree planting which emerged as consistent themes from the analysis of interview data. Table comprises a more detailed analysis of perceived physical constraints classified by respondent location, and Table 67 a more detailed analysis of human and organizational constraints.

Table 65: Summary of perceived constraints on street tree planting

Themes	Categories	Sub-categories
Physical		
Local conditions	Physical	Climate
		Coastal
		Soils (compaction)
	Urban form	Local character
		Type of development
Lack of space	Verge widths	
	Authority constraints	
Water	Limitations	Restrictions
		Drought
		Climate change
		Local conditions
	Species choice	
	Reduce planting	
Urban development	Urban infill	Crossovers
		Frontages
		Implications
	New subdivision	Tree damage
		Control
		Cost
Human		
Attitudes	Illegal removal	
	Litter	
	Overprotective	
Organizational		
Resources	Funding	Budgets
		Best practices
	Staff	Levels
		Skills, training
Strategic	Priorities, timing	
Externalities	State government	
	Developers	
Source: Compiled from participant interviews.		

Different Councils experience different constraints depending on locational factors such as physical setting (soils, climate, coastal etc.) or local urban character. However, according to one participant the main constraint comprises:

'Resources, and knowledge, and standards.' O6

Some of the main constraints on street tree planting relate to internal organizational factors, in terms of internal resourcing. However staffing resources are seen as more of an issue than funding and budgets.

'Internal resources. Just the maintenance requirements. We are trying to play catch up to understand what we have out there and need to maintain and look after, and therefore in the future replace or plan for replacement.' W3

Staffing issues include staffing levels (especially for establishment and maintenance), staff skills and knowledge, and the adherence to appropriate standards and specifications.

'Most people planting a tree have some idea, but best practices are not always followed.' O6

Some participants expressed a preference to cut back on the number of trees planted in preference to more successfully managing existing tree stock.

Another perceived constraint comprises water restrictions associated with drought and climate change.

'The obvious one is water.' E1

An increasing lack of space for tree planting is also a constraint, due to narrowing verge widths and the constraints imposed by various authorities.

'The lack of space in verges for planting is a particular problem.' O2

And according to one Council:

'The trees don't have a chance-if we follow the letter of the law. Which we obviously don't, because if we did the tree wouldn't exist.' E7

Table 66: Perceived physical constraints on street tree planting by respondent location

Response categories	Respondent																		
	Eastern suburbs							Western suburbs						Outer suburbs					
	1	2	3	4	5	6	7	1	2	3	4	5	6	1	2	3	4	5	6
Physical																			
Local conditions																			
-coastal								x											
-soil												x	x					x	
-compaction								x							x		x	x	
-climate																	x		
-character	x																		
-form of development		x											x						
Street space																			
Verge width	x					x			x			x			x				
Constraints	x	x			x	x	x			x				x					
Services																			
Impacts									x	x									
Longevity				x															
Water																			
Significant constraint	x		x							x									
Availability																			
-Restrictions	x																		
-Drought															x			x	
-Climate change			x														x		
-Local climate																	x		
Establishment															x	x			
Species choice	x		x		x											x		x	
Adaptation																		x	
Stop planting																		x	
Tree stock																			
Quality							x												
Urban development																			
Infill																			
Extent		x																	
Crossovers																			
Frontages																			
Greening implications				x														x	
New subdivision																		x	
Tree damage												x							
Lack of control																		x	
Cost factors																		x	
	1	2	3	4	5	6	7	1	2	3	4	5	6	1	2	3	4	5	6

Table 67: Perceived organizational constraints on street tree planting by repondent organization

Response categories	Respondent																		
	Eastern suburbs							Western suburbs						Outer suburbs					
	1	2	3	4	5	6	7	1	2	3	4	5	6	1	2	3	4	5	6
Human factors																			
Attitudes																	x		
Illegal removal																x	x		
Litter					x														
Over-protective						x													
Organizational																			
General																			x
Resources																			
Funding, budgets	x																		
-not an issue													x						
-best practices				x					x			x							
-water trucks												x							
Staffing																			
-levels							x			x									
-skills																			
-consistency								x											
-specialist skills	x						x												
-education							x												x
-specifications							x	x											
Reduced planting														x					
Strategic																			
Strategies					x														
Timing																x			
Priorities						x													
External																			
State govt. policy				x															
Development industry				x															
	1	2	3	4	5	6	7	1	2	3	4	5	6	1	2	3	4	5	6

11.3.5 Future threats to street trees

Question: What do you see as the main threats to the future of street trees in urban areas?

Table 68 provides a summary of the main threats to future street tree planting which emerged as consistent themes from the analysis of interview data. Table comprises a more detailed analysis of perceived threats classified by respondent location.

Table 68: Summary of perceived threats to future street tree planting

Themes	Categories	Sub-categories
Physical		
Urban development	General	
	Urban infill	Impervious surfaces
		Implications
	New subdivisions	Verge widths
		Footpath location
		Tree damage
		Bonding
Water	Limitations	Restrictions
		Drought
		Climate change
	Mature trees	
	Species selection	
Human		
Resident attitudes	Nuisance, damage, vandalism	Ageing population
	Liability	Fear of trees
	Illegal removal	
	Benefit awareness	
Organizational		
Planning	Priorities	
Management	Budgets	
Source: compiled from participant interviews.		

Two major factors were identified as future threats to urban street tree planting: water restrictions and urban development.

> *'Probably the biggest threat as I see it is the water restriction issue. Finding supplementary water for trees.' E6*

Water restrictions, as a consequence of drought or climate change, and loss of supplementary water sources for street trees, are seen as a current and future threat to both new tree plantings and to established mature trees. Future climatic change is also seen as impacting on species selection.

> *'And the climatic conditions you have to take into account. The selection of trees to install is quite limited if the future trends are taken into account.' O4*

The effects of climate change could also be more widespread.

'Increase in global temperatures-we've seen the effects of that already. If that is going to continue it will be even more difficult to establish our urban forest.' W5

The other main threat is seen as the nature of urban development. Infill development in established inner urban areas, and new land division in the outer developing suburbs.

'Infill is probably going to be the biggest threat.' O1

Urban infill (or consolidation) is characterized by 'two for one' subdivision of existing allotments, reducing private tree cover, but also impacting on street trees. More and wider crossovers, additional service connections and reduced frontages result in the loss of existing trees, and a reduction in opportunities for future street tree planting.

'I find the amount of development is increasing, and so we are dealing with street trees being lost, and also limiting the number of trees in front of properties as they are being subdivided. And peoples preference for double driveways or crossovers, 6m crossovers.' W1

Issues associated with urban infill are seen as a consequence of the planning approval process in which individual street trees are lost, without consideration of their role and value in contributing to the wider urban forest, and pressures for increased rate revenue in Councils.

'I think there is an issue with the subdivision of blocks. There's no doubt about it, it's usually the tree that will suffer in something like this. That to me would be the number one issue for street trees. They are under pressure to get that through planning. It's more rates.' W4

The wider implications of this urban infill process were also raised. Urban infill leads to smaller allotments, with less private open space, and less vegetation and tree cover. This will place more pressure on Councils for the provision of open space and urban greening in the public realm, including streets. But at the same time, existing street trees are being threatened, and it is becoming increasingly difficult to plant large trees in streets. The problem is exacerbated by an un-coordinated approach to urban consolidation that fails to provide additional public greening to compensate for the loss of private greening. Instead urban infill occurs in an incremental fashion which does not consider the cumulative effects of individual decisions on the urban forest. For urban densification needs to occur it should be accompanied by a coordinated program of urban greening.

'And its part of the government's 20/20 strategy to increase population through urban infill. So we've got that conflict coming in and we're trying to say, with the street tree, and they want big leafy green streets, how do you do that when you've got urban infill and you've got narrow footpaths.' W2

One participant summed up the situation as,

'Space and population-as the population becomes more dense we need more greenery for those benefits. But as the population gets more dense there's more pressure on space, more difficult to grow trees.' E4

In the developing outer urban areas the main threat is seen in the design and construction of new subdivisions. In these areas streetscape design and street tree planting are often undertaken by the developer rather than the Council. Developers are seen as being driven primarily by economic forces and may seek smaller allotments and reduced road widths to increase lot yields.

'With increasing urban development comes small blocks with narrow verges to get maximum block yield for the developers.' O2

Often the verge width will suffer under these pressures, with the needs of trees being given a low priority. This can result in reduced opportunities for tree planting, especially planting of larger tree species. Trees must also compete with the other services being squeezed into the available verge space.

'And the width of the verge itself has reduced. The road space now is seen as being a minimal thing. Developers try to maximize the size of the lots and squash the road and try and condense everything into a smaller footprint. Then trying to install the required range of infrastructure, from a developer's point of view, or from a provision point of view, stormwater, power, sewer, electricity, everything else, in a new subdivision tends to be underground, as well as a footpath on top of the ground. It doesn't leave much opportunity in a verge width of approximately 2 metres, and that's it.' O4

Instances were also cited in which developers have prepared initial concepts which include extensive tree planting, but the trees and original intention become lost in compromises in the long and drawn out development process, where competing demands for space or budgets result in reduced provision for trees.

'Not just in Council, within the development industry too, trees are seen as a necessary evil in some instances. A cost for developers. You need to watch out you don't get them trying to cut costs at that end. Trees are still the afterthought; they're not front of mind.' O6

A related issue in new subdivisions involves damage to trees after installation. Developers often plant street trees at the same time as other street infrastructure is installed, to assist in the marketing of allotments. However, during the subsequent housing construction process trees are damaged, with builders and contractors using the verge as a de-facto work site.

> *'I believe the trouble often is that street trees are installed just after the road and civil works is completed, and before the houses are even finished, so they tend to get trashed during construction.' O2*

And,

> *'The contractors see the verge as theirs, and if there is a tree in the road, then it's not big so it doesn't matter.' O4*

Some Council's are interested in pursuing a tree bonding option, subject to legal approval.

Table 69: Perceived threats to street tree planting by respondent location

Response categories	Respondent																			
	Eastern suburbs							Western suburbs						Outer suburbs						
	1	2	3	4	5	6	7	1	2	3	4	5	6	1	2	3	4	5	6
General										x	x								
Physical																			
Urban development																			
General					x			x											
Infill		x								x	x	x		x			x		
-impervious surfaces									x										
-implications of		x							x	x									
New subdivisions																			
-verge															x	x	x		
-footpath															x				
-tree damage															x		x		
-bonding																	x		
Space				x			x												
Infrastructure								x											
Water																			
Availability																			
-Restrictions			x			x		x					x						
-Drought		x					x								x				
-Climate change			x	x			x		x			x				x	x		x
-Mature trees			x				x		x						x	x			x
Species choice						x											x		
Other physical																			
Soils				x															
Diversity														x					
Human factors																			
Intolerance		x																	
Illegal removal															x				
Liability		x						x							x				
Fear of trees															x				
Unaware of benefits		x			x														
Organizational																			
Plan priorities					x							x							
Budgets		x																	x
Pruning					x														
Training					x														
	1	2	3	4	5	6	7	1	2	3	4	5	6	1	2	3	4	5	6

11.3.6 Most viable practices

Question: What practices do you consider to be most viable to grow healthier trees in urban streets, or to reduce tree/infrastructure conflicts?

Table 70 provides a summary of the most viable street tree practices which emerged as consistent themes from the analysis of interview data. Table comprises a more detailed analysis of perceived most viable physical practices classified by respondent location, and Table 72 a more detailed analysis of organizational practices.

Table 70: Summary of perceived most viable practices

Themes	Categories	Sub-categories
General		
	Combination of things	
	Getting the basics right	
Physical and design		
Streetscape design	Increased space	
	Opportunities	Narrower roads, wider verges
	Long term costs-benefits	
Below ground design	Increased rooting space	
	Best arboricultural practices	Soil, mulch etc.
	Soil preparation	Unamended soils
	Technical innovations	Trenching
		Root directors
		Tree guards
Infrastructure	Services	ABC
		CST
Water	Water management	Mulching
		Additives
	WSUD	Stormwater harvesting
		Permeable paving
		Subdivision design
Species selection	Size	Matching tree and site
	Selection criteria	Climate
Planting practices		
Tree stock	Quality	Rocket pots
	Size	
Aftercare	Establishment	
	Watering regime	
	Formative pruning	
Human		
Knowledge	Education	
Organizational		
Planning system,	Bonding	
Source: Compiled from participant interviews.		

To many Council's there is no single best practice, but rather a combination of many factors, which

'Would involve the accommodation of a lot of things.' W3

To others it is mainly a focus on getting the basics right, in terms of tree planting and establishment practices, rather than elaborate technical solutions.

> *'So just doing the right planting.' E3*

Many Council's therefore focus on best practices in terms of tree stock selection, planting practices and aftercare. Improving the quality of planting stock is seen as requiring a more critical approach to what is accepted, and building long term relationships with growers and suppliers.

> *'Selection, first and foremost. That's where we are falling down at the moment. I'm saying to blokes, don't just take delivery, go and pick them up, go and have a good look.' E7*

Aftercare is also considered critical.

> *'Again planting I think can make a lot of gains just in getting the right process. It's like children-the first formative years are important. You get it right and from then on the tree will be a good tree.' E7*

The two key aftercare concerns are water management and formative pruning.

> *'And again a proper maintenance regime particularly with water requirements.' O3*

> *'Formative pruning's the other one. Just getting it right for the early stage. That early, timely formative pruning will save you dollars down the track.' E7*

In terms of design practices, the major concern is to provide trees with more space in the design of the street. There is a need to provide realistic space based on the future size of the tree to minimize future conflicts.

> *'We try and give the tree as much room as we can. That's the key. Not trying to put a square peg in a round hole.' E3*

Particular attention needs to be given to the provision of adequate space around the base of the tree.

> *'The ideal would be to create more growing space around the trunk.' E6*

One option with potential is the creation of wider verges by narrowing traffic lane widths.

'I think, narrower streets with wider verges.' E7

Trees should also be afforded equal priority with other street infrastructure in the planning process.

> *'As long as they give us the space to grow trees. It's the trouble we seem to have, when you put your sewer, gas, electricity and everything else in. There should be an ideal design where they can put all that stuff out in the road, and give us room to plant our trees. They should plant the tree first and then put everything else around it somehow.' O1*

Allocating more space is also seen as an investment in terms of reducing long term costs.

> *'Recognition that if you plant a tree you get a certain level of management, maintenance costs associated with it. But if you can't get tree in there and give it enough room, you will get issues with it ' E2*

Provision of adequate space also extends below ground, in terms of providing adequate root volumes, appropriate soil preparation and using best arboricultural planting practices. Mulching and the use of additives such as Terra-cottem™ are also mentioned. Technologies such as root directors, structural soils and tree guards can also play a role in more confined urban settings.

> *'For me it would be the below ground space, opportunities. You can consider everything at surface level. But it's that whole below ground infrastructure you have to look at. The tree needs to establish a root network to support itself structurally, but also health wise. If we can try and provide something in that sense to develop a root base that is healthy, the tree will survive and cause less impacts into its environment, where the built form doesn't give much space for tree installations.' O4*

There is also a high level of interest in the possible application of Water Sensitive Urban Design (WSUD) techniques, particularly the use of practices which can provide trees with additional water sources in the face of the stresses imposed by water restrictions, drought and climate change. Two approaches of interest are stormwater harvesting and the use of permeable paving. Techniques need to be developed to divert road runoff to tree pits.

> *'Ideally get all that water running off roads and doing something more productive and efficient is essential.' W5*

More extensive use of permeable paving can also dramatically increase infiltration into the sub-soil.

> *'Ideally-have a surface that is permeable so that more water is absorbed by the tree stock.' W2*

Table 71: Perceived most viable physical practices by respondent location

Response categories	Respondent																		
	Eastern suburbs							Western suburbs						Outer suburbs					
	1	2	3	4	5	6	7	1	2	3	4	5	6	1	2	3	4	5	6
General																			
Many things				x								x							
Basics right			x							x			x						x
Design																			
Street space	x	x	x	x		x	x												
Opportunities						x	x							x	x				x
Cost benefits		x																	
Trees adaptable														x					
Priorities														x					
Tree pits																			
Size								x									x		
Best practices			x													x			x
Soil			x		x							x							
Trenching										x									
Root directors							x					x							
Guards																			
Services																			
Aerial Bundled Cable															x				
CST										x						x			
Water																			
Management	x										x								
Mulch						x													
Additives												x							
WSUD																			
General				x						x									
Harvesting				x		x			x			x			x		x		
Permeable paving				x					x										
Subdivision design																	x		
Tree species																			
General								x						x					
Match site																			x
Larger trees										x									
Appropriate size							x												x
Climate																		x	
Preferred species								x											
Trialing								x											
Perfect tree							x												
Planting practices																			
Stock																			
Quality			x				x	x								x			x
Rocket pots			x																
Size																		x	
Aftercare																			
General							x												
Establishment					x		x					x							x
Watering					x			x	x		x					x			
Pruning					x		x		x		x	x							
	1	2	3	4	5	6	7	1	2	3	4	5	6	1	2	3	4	5	6

Table 72: Perceived most viable organizational practices by respondent location

Response categories	Respondent																		
	Eastern suburbs							Western suburbs						Outer suburbs					
	1	2	3	4	5	6	7	1	2	3	4	5	6	1	2	3	4	5	6
Human factors																			
Education																			
-Community					x														
-Engineers					x														x
-Maintenance staff					x														
Organizational																			
Planning system					x													x	
Bonding															x				x
	1	2	3	4	5	6	7	1	2	3	4	5	6	1	2	3	4	5	6

11.3.7 Factors preventing the adoption of best practices.

Question: What factors do you consider may prevent or limit the adoption of these practices?

Table 73 provides a summary of the factors which may prevent the adoption of best practices, which emerged as consistent themes from the analysis of interview data. Table comprises a more detailed analysis of perceived factors classified by respondent location.

Table 73: Perceived factors preventing adoption of best practices

Themes	Categories	Sub-categories
Organizational		
Resources	Funding	Budgets
		Maintenance costs
		Best practices costs
		But will still plant trees
	Staff	Skills
		Turnover
Knowledge	Lack of knowledge	Knowledge of best practices
		Knowledge of engineers etc.
		Data base
	Lack of awareness of benefits	Strategic level, elected members
		Asset managers
		Community
		Demonstration projects
Management	Management practices	Priorities
		Change resistance
		Lack of forward planning
Externalities	Role of developers	
	Role of service authorities	
	Future liability	
Source: compiled from participant interviews.		

According to one inner suburban Council,

> *'I think it's a testing time over the next 5-10 years for the urban forest ' E6*

The main obstacles to the adoption of best practices are seen as relating to internal Council organization. The two key factors identified were: a lack of resources to implement best practices; and a lack of knowledge and awareness by others who may influence the tree planting process. Council resource issues cover two broad areas: funding resources and staff resources. Funding includes consideration of costs, budgets, maintenance and the cost of implementing improved practices. However cost is not always seen as a factor which would realistically prevent future tree planting.

'At the end of the day, it would probably go down to costing. Cost is always a factor. But I don't think it's going to limit us. 'E3

And,

'Money? It's not that-if the organization thinks it is important it will find the money, move it from other budget areas.' E2

Staff issues are considered significant, including a lack of adequate training, staff turnover, continuity and the role of contractors.

'I've tried training at the depot. It's a cultural thing as is often the case these days. It's a matter of getting them to actually understand.' E7

'It's difficult because the minute you get someone on the right track they leave-it's a never ending battle.' E7

To many tree managers, lack of education and knowledge by others is seen as the key obstacle to improved practices. This includes the need to educate other professions, such as engineers and planners, about basic tree requirements.

'And educate the engineers too about how they can modify a few areas of their design to accommodate your design. And here they are open to different ideas.' E1

And also awareness of what does constitute latest 'best practices' particularly through sharing of knowledge between Councils.

'How it all works. Are there other Councils undertaking these practices that you can get information from.' E1

Another key factor is the widespread lack of education regarding the benefits delivered by street trees. This includes at the strategic level of directors and elected members, and at the operational level of planners, engineers, and asset managers.

'Education …Information needs to be consistent and directed at the engineers and managers together with our elected members. If you have them on board you have a better understanding and a more sympathetic ear.' W5

Education of street tree benefits also needs to be directed to the wider community, to offset perceived negative attitudes to trees. One suggested answer is the use of demonstration projects.

> *'Maybe the answer is committing to one particular project and showing that as an example, you set the trend from that point on. It never ceases to amaze me how people have differing views on trees.' E7*

Other limiting factors relate to Council organization and priorities.

> *'From a Council perspective, only ourselves prevent or limit the adoption of the practices. 'E5*

Obstacles include engineering driven priorities in which trees are an afterthought, a dominant civil design culture, lack of flexibility and an asset management focus.

> *'People treating trees as an afterthought and not getting any professional advice on how to do it properly.' O6*

> *'We are like most Councils-the priority has been on the engineering focus. Trying to flip that around. It's the big challenge that we face.' E6*

> *'There's a huge push in local government for asset management plans at present. That's about maintaining your assets. Its fundamentally hard infrastructure related. I'm not sure trees even have to be looked at as part of the asset management plan. So there you are almost going against what the arborists and horticulturists want, which is that priority given to trees ' E6*

A related issue includes organizational resistance to change.

> *'Conservative nature of local government-in terms of what ifs and finances. Legitimate concerns, need data.' E4*

To some, street tree requirements need to be mandatory (as is the case for other types of infrastructure), rather than merely optional.

> *'It's got to be mandatory-in the specifications.' O6*

Finally there are also some other limiting factors outside of the Council organization which are less directly managed. One of these is the role of service authorities.

> *'However we always seem to fight with the service suppliers, the Origin's, ETSA's, Telstra's, the kerb and gutter guy.' That sort of thing that can undo so much good work.' E5*

Another externality is that of dealing with developers whose main focus may be on costs.

> *'I think cost is often the biggest one. The lot yield of areas by developers who want to maximize their yield. Because they are responsible for putting in the infrastructure, there's a huge cost of developing land. So that's the biggest issue, the financials.' O2*

Table 74: Perceived factors preventing adoption of best practices by respondent location

Response categories	Respondent																		
	Eastern suburbs							Western suburbs						Outer suburbs					
	1	2	3	4	5	6	7	1	2	3	4	5	6	1	2	3	4	5	6
Organizational																			
Lack of resources								x											
-Funding			x						x										
-Budgets										x									
-Cost					x											x			
-Maintenance		x						x											
-Best practices	x				x														
-Still plant trees			x								x								
Staff training							x	x											
Lack of knowledge																			
-general	x			x												x			x
-tree data base					x														
-engineers	x			x								x							
-best practices	x				x		x								x				
Low benefits awareness																			
-strategic level												x							
-asset managers												x			x				
-community							x												
-demo. projects							x					x							
Management practices																			
-responsibility					x														
-time					x														
-contract admin																x			
-engineering priorities						x											x		x
-change resistance				x			x												
-specifications																			x
External factors																			
-developer costs														x	x		x		
-future liability		x			x														
-future space		x																	
-species									x								x		
	1	2	3	4	5	6	7	1	2	3	4	5	6	1	2	3	4	5	6

11.4 Conclusions

Street trees are seen as providing the city with a wide range of environmental benefits, especially shade (Nowak & Dwyer 2007). However, from the point of view of residents, the most obvious benefits are visual, in terms of creating attractive and appealing streets and suburbs.

On the other hand, street trees can be associated with a number of problems, especially negative community attitudes to 'mess' and related issues, especially amongst the ageing population. Street trees are also involved in conflicts with urban infrastructure, both hardscape and services, both above and below ground (notably with electricity service providers).

A key constraint on street tree planting relates to Council resources, not just funding, but importantly human resources. Some Council's cite a need to cut back on planting levels to focus on more effective management of their existing tree stock. Lack of space in urban streets, both above and below ground, is also a constraint, with narrower verges and competition for space with a range of other authorities. Water restrictions, as a consequence of drought or climate change, are also a constraint on tree planting and on the survival of mature trees.

Lack of water is also seen as a potential threat to the future of the urban forest (Connellan 2008a). The other main threat is urban development itself, both urban infill and new subdivisions. Infill development results in loss of existing trees and loss of opportunities for future street tree planting (Hall 2008). In new subdivisions there may be a reduction in space available for street tree planting, especially larger trees, and damage to trees planted at the same time that other street infrastructure is installed. A more coordinated approach is required to ensure that urban greening occurs alongside urban densification.

Best practices which should be adopted would include a combination of many factors, rather than one 'silver bullet', as well as the need to 'get the basics right' (Harris *et al.* 2004). Better planting and establishment practices include the selection of better quality tree stock, and appropriate aftercare including watering regimes and formative pruning. Urban streets also need to be designed to provide more space for trees (Urban 2008). And trees should be given at least equal priority to other forms of street infrastructure (Hitchmough 1994). Considerable scope is also seen for the more widespread adoption of WSUD practices, especially the diversion of urban stormwater to street tree pits (Lawry 2008), and increased use of permeable paving (Ferguson 2005).

Many of the factors which may limit or prevent the adoption of these practices are seen as being part of internal Council organization, in two key areas: resources and knowledge. Funding is a constraint, but few Council’s envisage that lack of funding would limit or prevent future tree planting, if trees remain a priority with the community. Lack of knowledge by others is a key factor, both of the requirements of trees, and the benefits they deliver. This includes elected members, staff such as engineers, planners and asset managers, and the wider community.

12 A Model for Tree Sensitive Urban Design

12.1 Introduction

A key outcome of this thesis is the development of a draft Model for Tree Sensitive Urban Design (TSUD). The Model draws upon the findings of the literature review and the three original research studies contained in the thesis. The intention of the Model is to provide a framework document which can be adapted to local conditions by different tree management authorities, and then incorporated in local tree management or sustainable design strategies. The Model is identified as a 'draft' as it is intended to be circulated to a range of stakeholders for consultation purposes (which is beyond the scope of this thesis). The Model will also be a 'living' document in that additional practices will be added as future innovations occur.

12.1.1 Preamble

Street tree benefits

Street trees are a significant component of the urban forest, and provide the city with a wide range of social, economic and environmental benefits, with large mature trees maximizing those benefits. Trees help to ameliorate the urban climate and reduce the urban heat island effect through shading and evapotranspiration (McPherson *et al.* 1988). Trees oxygenate the air, remove pollutants, and sequester atmospheric carbon through photosynthesis (Brack 2002; Nowak *et al.* 2006). Trees also play an important role in the urban water cycle, their canopies intercepting rainfall and modifying runoff (Xiao 2002). Street trees can also enhance biodiversity and create corridors for wildlife. Urban trees are also recognized as having a range of social and psychological benefits, and the therapeutic and restorative effects of urban nature have been well researched (Ulrich 1984; Tarran 2006). Urban trees can also be of significant cultural and symbolic value. Long lived trees provide continuity and a link between generations. Trees, because of their scale, are a major element urban landscape design (Dwyer *et al.* 1994). The most commonly recognized benefit of street trees, however, relates to their visual and aesthetic role, in making our streets and cities more welcoming and pleasant places. Trees enhance a sense of identity, legibility and spatial definition in a street. Street trees provide a sense of human scale in urban streets, and a well designed avenue of trees can provide a unifying element in a visually diverse streetscape. Street trees are probably the most important factor in enhancing the amenity of the street for pedestrians and other users, by ameliorating microclimate, providing shade and shelter, and creating visual interest through form, colour and sense of movement (O'Brien 1993).Street trees are therefore more than just "aesthetic decoration" and are one of the most important factors in the design of an urban streetscape. According to Alan Jacobs in his book *Great Streets* (Jacobs 1993 p293).

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

The real economic value of urban trees is now also being recognised. Street trees have been shown to enhance residential property values, and increase visitation to business centres(Wolf 2005). Attempts have also been made to quantify the collective economic value of the urban forest, in the provision of environmental and other services (Killicoat *et al*. 2002).

Trees as green infrastructure

Street trees can, in fact, be viewed as a form of 'green infrastructure' delivering a range of environmental services to the city, alongside the 'grey infrastructure' of conventional engineering services (Wolf 2003). Street trees can deliver a range of tangible engineering benefits, such as increasing pavement life through shading, reducing demands on stormwater infrastructure through rainfall interception, and even providing a 'traffic calming' effect in urban streets. And unlike most single purpose infrastructure, a street tree can deliver multiple benefits from the valuable urban space it occupies. It is also evident that large trees deliver the greatest benefits, be it the potential for shading, rainfall interception or visual presence (Geiger 2003). Street trees, therefore, should be allowed to survive and grow to a mature size to maximize these benefits.

Street tree issues

In the past the needs of the tree have usually been left last in the design and construction process. Street trees tend to be squeezed into whatever space is left over, after all other functional and engineering requirements have been met (Thompson & Sorvig 2000). Consequences have included declining tree health, reduced tree life and increased mortality rates. Another consequence has been increasing conflicts between trees and their surrounding infrastructure (Costello &Jones 2003). It has been observed that, 'when the infrastructure wins, the tree fails, and when the tree wins, the infrastructure fails'. The response to these issues has too often been 'unsustainable' management practices such as tree removal, increased tree maintenance inputs, and ongoing infrastructure repair and replacement costs.

Biological tree needs

The biological needs of a street tree are essentially the same as those of a tree in the natural forest. The three key natural processes of photosynthesis, respiration and transpiration must be sustained. The following six requirements, above or below ground, are needed to sustain tree life and growth: oxygen, carbon dioxide, light, water, nutrients, and appropriate temperatures (Trowbridge and Bassuk 2004). To these could be added the requirement of adequate space, both above and below ground. Trees also play a significant role in a number of natural cycles which may be highly modified in urban areas: the water cycle, carbon cycle and nutrient cycles. Particular emphasis needs to be placed on the often forgotten 'landscape below ground' and the interactions of tree roots, soils and water in the urban environment (Craul 1992). We now have a better understanding of the morphology of tree roots, and a new model based on a shallow spreading 'root plate' rather than a deep, compact root ball (Coder 1998).

The hostile city

The city, however, comprises a very hostile environment for trees, in which these biological needs may be difficult to satisfy. In her 1984 book on urban ecological design, *The Granite Garden*, Anne Whiston Spirn identified the challenges facing urban trees (Spirn 1984). The list is long and includes competition for street space, (both above and below ground), infrastructure conflicts, vandalism and accidental damage, polluted air, temperature extremes and either too little or too much water. These problems are also often exacerbated by inappropriate planting practices (Thompson & Sorvig 2000). Two major issues are: planting trees in undersized tree pits dug in compacted soil; and surrounding trees with hard impervious surfaces. The hostile city, combined with inappropriate planting practices, can result in declining tree health, reduced tree life and tree deaths.

Probably the main concerns are those below ground, due to the highly modified and degraded nature of urban soils (Craul 1992). The most critical, and universal issue, is soil compaction and its impacts on tree root growth. Soil compaction has a number of impacts on tree growth, including: reduced surface infiltration; reduced soil water holding capacity; impaired drainage and water-logging; reduced soil aeration; and increased mechanical impedance to root extension. Tree pits dug in compacted soil act as virtual 'tree coffins' restricting roots to the tree pit and preventing the tree accessing the necessary soil volumes for growth. Tree pits dug in compacted soil can also suffer from the 'tea cup syndrome', the tree's root system being starved of oxygen as a result of water logging due to poor drainage from the soil in the tree pit, into the surrounding compacted soil. In addition street trees are usually planted in situations surrounded by hard impervious surfaces which limit the root systems access to water, oxygen and nutrients.

Thinking like a tree

When designing streets and other urban spaces for trees, we should therefore try to 'think like a tree'. The concept of Tree Sensitive Urban Design is proposed as a new, more sustainable paradigm for the design of urban areas to accommodate trees. Tree Sensitive Urban Design would include a set of objectives, guiding principles and 'best management practices' for the design of urban spaces both above and below ground.

12.1.2 Rationale

Tree Sensitive Urban Design is a new paradigm for the more sustainable management of trees in the urban environment which has developed in response to the negative environmental and other consequences of traditional engineering-driven streetscape design practices. These have: viewed trees as having no real value beyond 'aesthetic decoration'; given trees a lower priority than other forms of urban infrastructure; and have not recognized the biological needs of trees in the design process. The consequences have included: loss of trees and tree canopy cover and associated benefits; increased tree/infrastructure conflicts; and increased inputs to maintain and replace both trees and infrastructure. TSUD is based on a new attitude, that trees are a valuable resource, delivering real benefits to the city, which should have equal status to other forms of infrastructure. It is also based on a new set of practices aimed at better integrating the biological needs of trees into the planning and design of urban areas

The following sections comprise the key elements of the TSUD Framework: objectives, principles, and best management practices (BMP's). Practices are either structural (related to physical planning and design), or non-structural (related to organizational factors such as management practices). Non-structural practices may play a key role in modifying organizational and community attitudes, facilitating the implementation of the structural practices (Lloyd *et al.* 2002). The list of best management practices will also grow as new innovative practices are developed and adopted.

In developing a TSUD strategy for a specific locality, reference should be made to local WSUD frameworks as a guideline. In the case of South Australia this comprises the *Water Sensitive Urban Design* (*WSUD) Technical Manual Greater Adelaide* (DPLG 2008), which includes objectives for WSUD in the context of the Adelaide region. TSUD should also be integrated and linked with wider State government, local government and national government goals and strategies for urban development, including both new urban development and urban infill. In South Australia this would include the *30 Year Plan for Greater Adelaide* (DPLG 2010). TSUD targets, such as urban tree planting numbers and canopy cover requirements, should also be integrated with other government sustainable development targets. For example in South Australia the *Integrated Natural Resources Management Plan for the Greater Adelaide and Mount Lofty Ranges Region* (Government of South Australia 2008). Pathways through the existing development system should also be identified, in terms of mandating general TSUD objectives and principles, and identifying specific criteria and standards related to urban tree planting. In South Australia this could comprise the *Development Plan* for a particular local government area, prepared under the *Development Act* 1993 (Planning SA 2008).

12.2 Vision and objectives

Key TSUD planning and design objectives include:

a) Maximize the social, economic and environmental benefits delivered by urban trees.
b) Increase tree canopy cover in urban areas.
c) Grow an urban forest of healthy, long lived trees.
d) Reduce conflicts between trees and the surrounding urban fabric.

12.3 Guiding principles

12.3.1 Structural principles

Structural principles relate to the planning and design of the physical street tree environment. These include:

a) Design around the biological needs of the tree (thinking like a tree).
b) Maximize available space for trees above ground.
c) Maximize available space for trees below ground.
d) Providing trees with the necessary resources for growth (including water, light, oxygen and nutrients).
e) Minimize tree/infrastructure conflicts.
f) Select the 'right tree for the right place'.
g) Integrate trees with Water Sensitive Urban Design initiatives.
h) Adopt best arboricultural tree selection, planting and establishment practices.
i) Adopt best arboricultural practices for managing established trees.
j) Adopt best arboricultural practices for managing tree senescence, removal and replacement.

12.3.2 Non-structural principles

Non-structural principles relate to management and policy considerations which limit or enhance the uptake of improved practices. These include:

a) Value. Recognize the true value of trees at a strategic and policy level.
b) Resources. Allocate appropriate budgets for both tree planting and maintenance.
c) Collaboration. Adopt a collaborative, interdisciplinary design approach (including the disciplines of design, engineering and arboriculture).
d) Priority. Give street trees at least equal priority to other forms of urban infrastructure.
e) Standards. Include tree requirements in the relevant engineering standards and specifications.
f) Knowledge. Educate engineers and others about the biological requirements of trees.

g) Knowledge. Educate elected Council members, staff and the community about urban tree benefits.

h) Knowledge. Educate all stakeholders on the environmental services provided by trees in and urban landscapes.

i) Knowledge. Educate all stakeholders on the economic value of those environmental services.

12.3.3 Tree literate design

When planning and designing urban streets we should try to 'think like a tree'. To encourage the growth of large and healthy trees, the major parts of the tree structure, both above and below ground, must be considered. This can be conceptualized in terms of three 'zones' presented in Table 75, the zone above ground, the ground plane zone, and the below ground zone. The above ground zone must accommodate the spatial and biological requirements of the tree canopy and trunk. The ground plane is the vital zone in which water, nutrients and oxygen enter the soil. Its permeable qualities should be maintained by limiting compaction and the extent of hard impervious surface cover. It is also the critical zone where the tree trunk meets the ground. The below ground zone must accommodate the biological and spatial requirements of the tree's root system.

Table 75: Street tree management zones

Tree management zone	Tree elements	Natural processes	Biological requirements
Above ground zone	Canopy Trunk	Transpiration Photosynthesis Respiration	Sunlight Carbon dioxide Appropriate temperatures Space
Ground plane zone	Basal flare Zone of rapid taper	Structural stability Respiration	Water, gaseous and nutrient exchange Space
Below ground zone	Root system	Respiration Water, nutrient uptake	Oxygen Water Nutrients Appropriate temperatures Soil volume Soil bulk density/ compaction

Table 76 provides a summary of the main issues and constraints in each zone, for long term tree health and potential infrastructure conflicts.

Table 76: Urban tree issues

Tree management zone	Tree health issues	Infrastructure issues
Above ground zone	Urban microclimate Shading Canopy competition-buildings Canopy competition-other trees Accidental damage Vandalism	Overhead powerlines Traffic engineering standards Buildings and structures Competition for space
Ground plane zone	Compaction Impervious surfaces-oxygen, water, nutrient exchange	Proximity to hardscape Completion for street space
Below ground zone	Compaction Waterlogging Nutrient status Required soil volumes Available water	Underground services Building footings-soil shrinkage

Figure 54 illustrates the concept of the three street tree management zones.

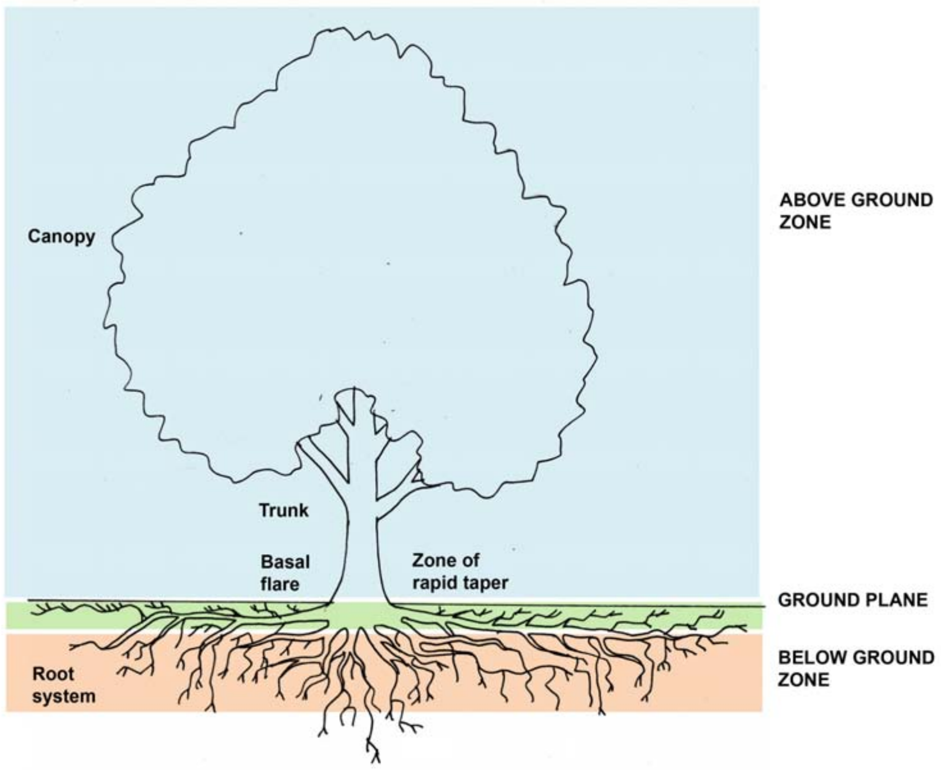

Figure 54: Tree management zones

Tree crown. There is a direct relationship between the above and below ground parts of the tree. The tree canopy provides the overall tree with 'food' through photosynthesis. It also acts as a 'pump' drawing water from the soil to evaporate from the leaves as part of the transpiration process. The tree crown requires access to sunlight for photosynthesis and may not tolerate excessive shading. It may also be subject to damage from the urban microclimate, and accidental or deliberate human damage. As it grows and spreads it may interact with overhead services, buildings and other tree crowns. This may result in infrastructure conflicts or restricted canopy growth. Sufficient space must be allocated to accommodate the mature tree canopy. Restricted canopy growth will effect overall tree growth and health.

Tree trunk. A strong, healthy trunk is required to support the tree canopy and provide a conduit for the movement of water and nutrients between the root system and the canopy. As the tree grows the trunk expands in diameter. Tree trunks will also sway in the wind and may be damaged by adjacent objects. Tree trunks may also be subject to deliberate or accidental human damage, especially when young. Sufficient space must be allocated for the mature tree trunk including sway.

Trunk flare. As a tree matures, a pronounced swelling or flare develops at the point where the tree trunk reaches the ground, which contributes to the tree's structural stability. The trunk flair varies between tree species. The tree base can expand at more than twice the rate of the main trunk diameter. Any hard surfaces installed in this zone can result in conflicts damaging to both the infrastructure and the tree. Sufficient space should be allocated at the ground surface to accommodate the likely trunk flare.

Zone of rapid root taper. In a zone approximately two metres around the trunk base, tree roots emerge from the trunk and divide into thick structural roots, rapidly tapering to finer roots. Most damage to hardscape will occur in this zone, which should be kept free of infrastructure to reduce damage and encourage long term tree health.

Root zone. In the root zone the tree's root system explores the soil for water and nutrients. Respiration occurs in all parts of the tree including the root zone, so access to oxygen is a key limiting factor. We now have a better understanding of the morphology of urban tree roots. Contrary to popular belief, most trees do not typically develop a compact root ball with a deep tap-root, but rather a shallow 'root plate' spreading 2-3 times the canopy diameter. Most roots are, in fact, found in the top 300-600 mm of soil, where conditions of moisture, nutrients and oxygenation are most favourable for growth. An important relationship exists between the size of the tree canopy and the volume of rootable soil required to support growth. Importantly, trees need access to large soil volumes to provide their daily water requirements. Appropriate soil volumes should be provided, and the tree provided with the resources necessary for growth. The root zone should be protected from compaction, and ideally the root zones of individual trees should be interconnected for healthier growth.

12.4 Best Management Practices

Current and emerging best practices in more sustainable streetscape design and street tree planting include the following section.

12.4.1 Structural best management practices

Figure 55 provides a graphic summary of the scope of structural best management practices. Structural principles relate primarily to the planning and design of the physical street tree environment.

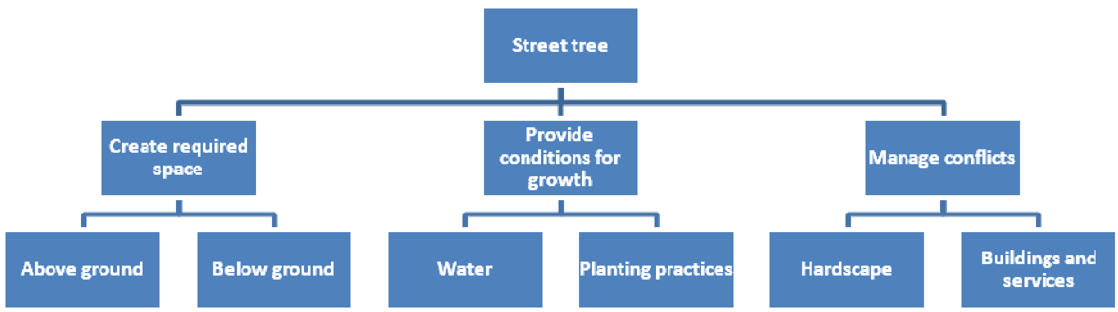

Figure 55: Structural practices

Above ground design

Street trees are but one element in the urban streetscape and must compete for valuable urban space with a range of other physical infrastructure and functions. Tree species selections and planting locations are also often constrained by setback or clearance requirements from other urban infrastructure, including hardscapes, underground and overhead services. Management of conflicts with overhead power lines constitutes a significant impact on street trees. Safety requirements of traffic management authorities, including clear zones and intersection sightlines, are also a significant constraint on tree planting and management. Many of these requirements may be summarized in local authority codes. In addition trees often compete with other urban activities for valuable footpath or road space, including pedestrian access, cycling and outdoor dining.

Trees should be given equal status to other physical elements and land uses in the streetscape, and provided with the required space to allow for healthy growth to a mature size, while minimizing conflicts with surrounding infrastructure. The largest possible ground space should be allocated for each tree, to maximize porous surfaces and increase separation from surrounding hardscapes. Streets can be designed or reconstructed to provide greater opportunities for tree planting, and more space for individual trees. Alternative tree planting locations can also be explored, which may require road traffic and service authorities to review their setback requirements. Best management practices for streetscape design are summarized in Table 77. For each practice a cross-reference is provided to the relevant thesis chapter or section.

Table 77: Best management practices-streetscape design

Strategy	Practice	Thesis cross-reference
Enlarged cutouts	Continuous open verge	Ch. 6.3.6
	Individual tree pits	Ch. 6.3.6
	Footpath narrowing	Ch. 6.3.6
Footpath widening	Carriageway narrowing	Ch. 7.2.5
	Traffic/parking lane removal	Ch. 7.2.5
	Alternative street templates	Ch. 7.2.5
	Buildouts	Ch. 3.4
Widened verge space	Narrow footpaths	Ch. 6.2.5
	Curved footpaths	Ch. 7.2.5
	No footpaths	Ch. 7.2.5
	Footpath one side only	Ch. 6.2.4
Alternative tree locations	Back of kerb	Ch. 3.4
	Property boundary	Ch. 7.2.5
	Parking lane	Ch. 3.4
	Median	Ch. 3.4
	Private property	Ch. 3.4
Planting geometry	Avenue	Ch. 3.4
	Opportunistic	Ch. 6.3.6
	Informal planting	Ch. 6.3.6
	Block/group planting	Ch. 6.3.6

Below ground design

Traditionally urban street trees have been planted in small tree pits dug in compacted soil with tree roots limited to the confines of the pit, unable to access the resources necessary for growth. However there is a clear relationship between the size of a tree and the size of its root system and below ground space. Restricted soil volumes have had a number of consequences including dwarfing, declining tree health, and increased tree mortality. Attempts have been made to quantify the relationship between the size and required soil volumes. These have been based on either empirical observations, or calculations of soil volumes required to meet the water demands of the tree. While the results vary widely, it is clear that most urban planting situations provide useable soil volumes well below the optimum, or minimum requirements of the tree. A priority should be to maximize the underground space and rootable soil volume available to the tree. It must also be assured that the qualities of the below ground environment are favourable for tree growth, including soil drainage, oxygenation and nutrient status.

It is possible to extend the rooting zones of trees in confined urban settings, including extending the rooting zone below surrounding pavements. Options include creating shared rooting volumes in the form of tree islands or linear root trenches connecting individual tree pits. Structural soils are one attempt to meet the conflicting requirements of providing soils below pavements that meet both the load bearing requirements of engineers and the biological requirements of trees. Structural soils comprise a family of different soil types, the most well known being those with a load bearing stone matrix. In recent years structural soils have been criticized for a number of reasons including the fact that up to 80% of the mix may comprise inert stones, with only 20% of rootable soil volume. A second generation option for extending rooting zone below pavements comprises suspended pavements in which a concrete slab is cantilevered over a tree pit root trench. An ‘emerging’ third generation approach comprises the installation of a matrix of load bearing plastic cells, with the soil filled voids comprising up to 90% of the below ground volume. Such approaches are expensive but may be cost effective in confined urban settings where tree planting is mandated. The ideal approach, however, is for the initial design of the street to create the largest volumes of uncovered soil possible. Attention should also be given to the design of the tree pit surface to reduce the risk of compaction and enhance its porous properties.

In summary, the space below ground should be designed to provide increased soil volumes for trees, and to better provide the resources necessary for growth. Best management practices for below ground design are summarized in Table 78. For each practice a cross-reference is provided to the relevant thesis chapter or section.

Table 78: Best management practices-below ground design

Strategy	Practice	Thesis cross-reference
Soil volume calculations	Empirical	Ch.6.3.2
	Water demand models	Ch.6.3.2
Increased tree pit volume	Enlarged tree pits	Ch.6.3.2
	Continuous root trench (verge)	Ch.6.3.6
	Block planting	Ch.6.3.6
	Raised planter/ berm	Ch. 6.3.6
Rooting environment	Unamended soils	Ch. 6.3.3
	Soil replacement	Ch. 6.3.3
	Soil amendment	Ch. 6.3.3
	Compaction reduction	Ch. 6.3.3
	Improved drainage	Ch. 6.3.5
	Soil oxygenation	Ch. 6.3.6
	Increased nutrients	Ch 6.3.6
Extending below paving	Tree pit extension	Ch. 6.3.6
	Continuous trench	Ch. 6.3.6
	Structural soil	Ch. 6.3.4
	Suspended pavement	Ch. 6.3.6
	Structural root cell	Ch. 6.3.6
Containerized	Above ground	Ch. 6.3.6
	Below ground (vault)	Ch. 6.3.6
	Bunker	Ch. 6.3.6
Tree pit design	Best practice tree pit	Ch. 6.3.5
Tree pit surface	Increased surface area	Ch. 6.3.5
	Tree grate	Ch. 6.3.5
	Porous aggregate	Ch. 8.5.1
	Mulching	Ch. 6.3.2
	Underplanting	Ch. 6.3.5

Water management

Urban street trees face additional challenges compared to trees planted in open situations such as parks, including increased evaporative demands and restricted water supply. Street tree water management can be conceptualized in terms of water supply and demand. Water demand is a function of the transpiration mechanism which is influenced by a range of climatic factors. The urban climate and microclimate, including the urban heat island effect, makes high evaporative demands on trees. The natural water cycle is also highly modified in urban areas and street trees must often survive with a restricted water supply. This is exacerbated by the long term water restrictions being imposed in most Australian cities in response to drought and climate change. Water management for urban street trees is based on the concept of providing an adequate soil moisture reservoir to meet the year long needs of the tree including extended periods without rainfall. A basic principle therefore is to provide street trees with the maximum soil volumes.

In times of drought and water restrictions there is a need to find better ways to deliver water to street trees. Practices to meet the water demands of trees include more effective water management practices for both new and mature trees, and improved tree pit designs that provide appropriate soil volumes and enhanced infiltration. This may include integration with innovative WSUD practices, which have recently been adapted to the urban streetscape scale, and which can provide benefits to both the tree and the urban water cycle. Best management practices for water management are summarized in **Table 79**. For each practice a cross-reference is provided to the relevant thesis chapter or section.

Table 79: Best management practices-water management

Strategy	Practice	Thesis cross-reference
Water conservation	Mulching	Ch. 6.4.5
	Soil additives	Ch. 6.4.5
	Turf replacement	Ch. 6.4.5
	Watering regime	Ch. 6.4.5
	Tree species selection	Ch. 6.4.5
Water management	Water demand calculation	Ch. 6.4.4
Alternative sources	Stormwater	Ch. 6.4.5
	Recycled water	Ch. 6.4.5
	Bore water	Ch. 6.4.5
Porous surfaces	Soft surfaces	Ch. 8.5.1
	Porous aggregates	Ch. 8.5.1
	Eco-paving systems	Ch. 8.5.2
	Sub base storage	Ch. 8.5.2
Bioretention systems	Basin	Ch. 8.4.1
	Swale	Ch. 8.4.1
	Tree pit	Ch. 8.4.1
Passive irrigation	Tree pit in road	Ch. 8.4.3
	Aggregate trench	Ch. 8.4.1
	Watering ring/pipe	Ch. 8.4.1
Stormwater diversion	No kerb	Ch. 8.4.1
	Permeable kerb	Ch. 8.4.1
	Kerb inlet	Ch. 8.4.1
	Water table inlet	Ch. 8.4.1
Active irrigation	Sub-surface storage	Ch. 8.5.2

Infrastructure design

In urban situations conflicts often arise between street trees and the surrounding infrastructure, including hardscapes, buildings and services (both above and below ground). In situations where conflicts occur between trees and infrastructure, the tree is usually blamed, resulting in severe pruning, tree removal and possible restrictions on further tree planting. Tree-infrastructure conflicts, however, can also be resolved through improved infrastructure design, given that street trees are a valued component of the urban environment. In the past, resolution of conflicts has tended to be tree based, focusing on tree species selection, planting setbacks and pruning practices. An alternative engineering based approach would be more beneficial to promoting the interests of the urban forest. This would include engineering solutions to tree and infrastructure conflicts, in terms of both service locations and their design. It would also include a re-examination of authority standards which recognizes both functional and safety requirements and the community benefits delivered by street trees.

Conflicts between tree roots and the hardscape of streets is probably the main issue to be dealt with by urban tree managers, especially in constrained urban sites. Hardscape damage is a concern in many cities, not just in terms of repair costs, but also with public liability. In addition the tree also suffers in such conflicts, which can lead to tree removal and constraints on future planting. The cause of tree root damage can be either direct or indirect, and is often due to the favourable conditions beneath pavements installed over a compacted sub base. Strategies to minimize conflicts can be tree based, infrastructure based or rootzone based. The key to success, however, is in the early design stages, ensuring that trees are giving realistic space, both above and below ground, for root development without impacting on the adjacent hardscape.

Table 80: Best management practices-hardscape conflicts

Strategy	Practice	Thesis cross-reference
Tree based	Species selection	Ch. 7.2.4
Infrastructure based		
Materials	Increased strength	Ch. 7.2.5
	Flexibility	Ch. 7.2.5
Planting geometry	Increased space	Ch. 7.2.5
	Horizontal separation	Ch. 7.2.5
	Vertical separation	Ch. 7.2.5
Footpath options	Narrow footpath	Ch. 7.2.5
	Curved footpath	Ch. 7.2.5
	Buildouts	Ch. 7.2.5
	Footpath by kerb	Ch. 7.2.5
	No footpath	Ch. 7.2.5
	Footpath easement	Ch. 7.2.5
Street design options	Reduced carriageway width	Ch. 7.2.5
	Tree islands	Ch. 7.2.5
Root zone based	Soil water management	Ch. 7.2.6
	Gravel layer	Ch. 7.2.6
	Root barriers	Ch. 7.2.6
Remedial practices	Repair	Ch. 7.2.7
	Root pruning	Ch. 7.2.7
	Tree removal	Ch. 7.2.7
	No replacement	Ch. 7.2.7
Asset management	Synchronized asset life	Ch. 7.2.5

Prevention and management of conflicts with overhead power lines constitute a significant impact on street trees. Tree based strategies may be detrimental to trees and limit tree species choice and planting locations. Infrastructure based strategies such as undergrounding and aerial bundled cable are preferable, however major service redesign or relocation to better accommodate street trees may be costly.

Tree entry into underground services, especially sewer lines, is a universal problem. However initial root entry is often due to failure of the infrastructure. Avoidance measures by authorities may focus on restricting tree planting in terms of species and separation distances. A more satisfactory approach, however, is the appropriate design of the infrastructure to allow both trees and services to co-exist in urban streets.

Trees are sometimes implicated in building damage, due to their effects on soil moisture levels and expansion and contraction in reactive clay soils. However trees may only be one of a number of factors involves in such damage, and are often blamed without any supporting evidence. Interactions of tree roots, soils and building footings are not well understood and current standards are often based on empirical observations only. A common strategy to minimize damage is a separation distance based upon mature tree height. However if such controls were rigorously applied there would be few trees in cities especially with the trend to smaller allotment sizes and urban densification. The preferred approach would be one which allows trees and buildings to co-exist, with more appropriate footing designs based on a sound knowledge of tree, soil and footing interactions.

Best management practices for services and buildings are summarized in Table 81. For each practice a cross-reference is provided to the relevant thesis chapter or section.

Table 81: Best management practices-services and building conflicts

Strategy	Practice	Thesis cross-reference
Above ground services		
Tree based	Species selection	Ch. 6.2.7
	Separation distance	Ch. 6.2.7
	Pruning	Ch. 6.2.7
Infrastructure based	Routing	Ch. 6.2.7
	Relocation	Ch. 6.2.7
	Undergrounding	Ch. 6.2.7
	ABC	Ch. 6.2.7
Below ground services		
Tree based	Species selection	Ch. 7.4.4
	Separation distance	Ch. 7.4.4
Infrastructure based	Design and construction	Ch. 7.4.4
	Root barriers	Ch. 7.4.4
Buildings		
Tree based	Species selection	Ch. 7.3.7
	Separation distance	Ch. 7.3.7
	Tree removal	Ch. 7.3.7
	Water management	Ch. 7.3.7
Infrastructure based	Footing design	Ch. 7.3.7
	Root barriers	Ch. 7.3.7

Tree species selection

Tree species selection remains a key tool for urban tree managers in growing healthy trees and reducing infrastructure conflicts. A key aim is to better match trees and planting sites, selecting ‘the right tree for the right place’. A successful street tree must meet a wide range of selection criteria; however key criteria include size, tolerance of hostile sites, and drought resistance in times of water restrictions and climate change, and root system characteristics that may limit conflicts with surrounding infrastructure. Best management practices for tree species selection are summarized in Table 82. For each practice a cross-reference is provided to the relevant thesis chapter or section.

Table 82: Best management practices-tree species selection

Strategy	Practice	Thesis cross-reference
General	Largest tree/ canopy possible	Ch. 4.2.4
	Proven species	Ch. 10.4.5
Restricted sites	Smaller trees at closer spacings	Ch. 10.4.5
	Match tree to site	Ch. 10.4.5
	Upright form	Ch. 9.3
Hostile sites	Shade tolerance	Ch. 5.2.3
	Compaction tolerance	Ch. 5.4.4
	Inundation tolerance	Ch. 5.3.3
Limited water	Drought tolerance	Ch. 6.4.5
Infrastructure conflicts	Rooting habit	Ch. 8.4.1
	Trunk fare and root buttress	Ch. 8.4.1
Overhead services	Tree size	Ch. 6.2.7
Diversity	Species diversity	Ch. 3.3
	Age diversity	Ch. 3.3

Planting and establishment practices

Adopting sound arboriculturally based planting and establishment practices is the key to growing healthier longer lived trees. Best practices include a combination of many factors, rather than one 'silver bullet', including the need to 'get the basics right'. Better planting and establishment practices include the selection of better quality tree stock, and appropriate aftercare including watering regimes and formative pruning. Best management practices for street tree planting and establishment are summarized in Table 83. For each practice a cross-reference is provided to the relevant thesis chapter or section.

Table 83: Best management practices-planting and establishment

Strategy	Practice	Thesis cross-reference
Tree stock selection	Size	Ch. 11.3.6
	Quality	Ch. 11.3.6
Site preparation and planting	Best practice tree pit	Ch. 6.3.5
	Unamended backfill	Ch. 6.3.4
	Additives	Ch. 6.4.5
	Watering berm	Ch. 6.3.5
	Water well	Ch. 6.4.5
	Mulching	Ch. 6.3.4
	Decompaction	Ch. 6.3.3
Aftercare	Establishment program	Ch. 11.3.6
	Watering regime	Ch. 11.3.6
	Formative pruning	Ch. 11.3.6
	Bonding	Ch. 11.3.6

12.4.2 Non-structural best management practices

Figure 56 provides a graphic summary of the scope of non-structural best management practices. Non-structural principles relate to management and policy considerations which limit or enhance the uptake of improved practices.

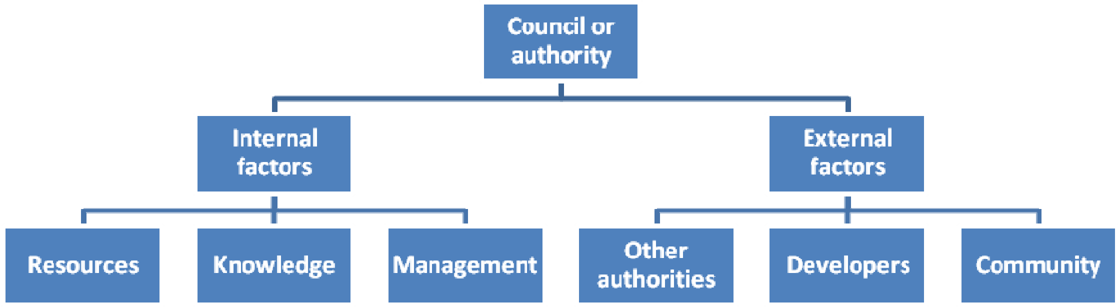

Figure 56: Non-structural practices

Non-structural practices include factors that are internal to the tree management organization (such as organizational resources) and those external to the organization (such as the policies of service authorities) but which still impact on the organization's management of the urban forest.

A number of external authorities impact upon the management of the urban forest. Street trees often conflict with urban infrastructure, resulting in tree based solutions (such as pruning, removal or prohibition) which are detrimental to the urban forest. Ideally trees should be given at least equal priority to other forms of street infrastructure.

The other main external threat to the urban forest is urban development, both urban infill and new subdivisions, as a result of the activities of developers, Councils and state planning authorities. Infill development results in the loss of existing trees and loss of opportunities for future street tree planting. In new subdivisions there may be a reduction in space available for street tree planting, especially larger trees, and damage to trees planted at the same time that other street infrastructure is installed. A more coordinated approach is required to ensure that urban greening occurs alongside urban densification.

Street trees provide the community with a wide range of environmental benefits. However they may also be perceived negatively by the community, especially attitudes to ‘mess’ and nuisance especially amongst the ageing population. This represents a potential threat to the urban forest to be managed by Council through strategies such as education.

Some of the key constraints on street tree planting relate to internal Council organization: resources (not just funding, but importantly human resources); knowledge; and management practices. Funding is a constraint, but few Council’s would envisage that lack of funding would prevent future tree planting, if trees remain a priority with the community. Lack of knowledge by others is a key factor, both of the requirements of trees, and the benefits they deliver. This includes elected members, staff such as engineers, planners and asset managers, and the wider community. These groups should be targeted for education regarding urban tree benefits and requirements. Management practices which may require improvement include giving trees greater status and priority, overcoming resistance to change, and fostering the adoption of more innovative best management practices.

Non-structural best management practices are summarized in Table 84. For each practice a cross-reference is provided to the relevant thesis chapter or section.

Table 84: Non-structural best management practices

Strategy	**Practice**	**Thesis cross-reference**
External factors		
Service authorities	Tree priorities	Ch. 10.3.4
State planning authorities	Strategic recognition of urban forest at State level	Ch. 11.3.4
	Greening requirements in urban consolidation policies	Ch. 11.3.6
	Include trees in planning legislation	Ch. 11.3.6
	State/national standards for trees	Ch. 11.3.6
Community	Education of tree benefits	Ch. 11.3.7
	Demonstration projects	Ch. 11.3.7
	Consultation	Ch. 11.3.7
Developers	Bonding trees-developer pays for damage/loss	Ch. 11.3.6
Internal factors		
Support	Strategic level support	Ch. 11.3.7
Resources	Budgets and funding	Ch. 11.3.7
	Staff	Ch. 11.3.7
	Internal standards	Ch. 11.3.7
Knowledge	Arboricultural staff training	Ch. 11.3.7
	Education-tree requirements	Ch. 11.3.7
	Education-benefits	Ch. 11.3.7
Management practices	Priorities	Ch. 11.3.7
	Innovation	Ch. 11.3.7
	Collaboration	Ch. 11.3.7

12.5 Conclusion

The Model for Tree Sensitive Urban Design provides an alternative paradigm for the more sustainable planting and management of the urban forest, based on a set of guiding principles and structural and non-structural best management practices. It is envisaged that Tree Sensitive Urban would be implemented in a similar fashion to the WSUD paradigm, through a process of 'institutionalization' including technical innovation, community acceptance, economic feasibility and 'proof of concept'.

13 Final conclusions

13.1 Introduction

The following chapter provides a brief synthesis of the study findings and final conclusions, including recommendations for future research.

13.2 Synthesis

Table 85 and Table 86 provide a comparison of the key findings from the three original research components of the study.

Table 85: Synthesis of study findings -perceptions

	Capital Cities Study	**National Practitioner Study**	**Metropolitan Adelaide Study**
Study methodology	Case study. Unstructured interviews.	Quantitative. Online survey.	Structured in-depth interviews.
Attitudes and perceptions			
Benefits	Visitor amenity. City image. Shade.	Visual/aesthetic. Environmental (shade). Amenity.	Character and amenity. Environmental-shade.
Issues	Succession planning. Lack of diversity. Water. Other planning authorities.	Infrastructure damage. Tree health and longevity. Liability/risk.	Negative community attitudes. Infrastructure conflicts.
Constraints	Hostile city environment. Lack of space. Narrow streets. High pedestrian volumes. Shaded streets. Hard surfaces. Underground services. Underground structures. Water.	Lack of space. Lack of species choice.	Resources-funding, staff. Lack of space. Water restrictions.
Threats	Competition for footpath space. Reduced building setbacks. Planting practices. Water-mature trees. Increased services. Species specific disease.	Service providers (especially electrical) and traffic authorities. Lack of knowledge by others.	Urban development-urban infill and new subdivisions. Water restrictions.

Table 86: Synthesis of study findings-practices

	Capital Cities Study	**National Practitioner Study**	**Metropolitan Adelaide Study**
Practices			
Streetscape design	Footpath widening Planting in parking lane. Median planting. Narrow streets.	Median planting. Increased planting site size. Group planting. Footpath widening.	Increased verge space. Road narrowing.
Below ground	Maximize space. Root trench. Structural soils. Suspended slabs. Soil specifications. Soil cells. Tree vaults. Above ground containers.	Design on arboricultural principles. Increased soil volumes. Structural soils. Some innovations not widely adopted.	Increased rooting space. Best arboricultural practice. Many things. Basics.
Tree pit surface.	Granitic sand. Resin bonded gravel. Signature tree grate.	Question not asked.	Porous surfaces.
Water management	Mature tree watering. Alternative sources. Turf alternatives.	Alternative sources.	Mulching. Additives.
WSUD	Local climatic context. Bioretention systems. Infiltration systems. Stormwater harvesting. Permeable paving.	Pervious surfaces. Passive watering. Raingardens. Some innovations not widely adopted.	Stormwater harvesting. Permeable paving.
Hardscape.	Conflicts with durable hardscape. Increased tree trunk separation. Root barriers.	Primarily root barriers. Flexible pavements. Separation of tree/hardscape.	Increased space.
Services	Service relocation-cost. Root barriers. Undergrounding. Aerial bundled cable.	Undergrounding. Aerial bundled cable. High relocation costs.	Common service trench. Aerial bundled cable.
Tree species selection	Historical palette. Shade tolerance. Narrow streets. Increasing diversity.	Proven species. Drought tolerance. Long lived.	Match tree size and site. Climate.
Planting and establishment practices	Planting time. Tree size. Correct planting depth. Establishment-watering practices. Contractors.	Question not asked.	Tree stock. Aftercare-watering, pruning.
Organizational	Political support. Resident support. Maintenance practices. Contractor supervision.	Need for improved Council tree management. Negative community attitudes.	Improved planning system. Knowledge.
Factors limiting adoption	Cost. Lack of greenfield sites.	Resistance by engineers etc. Council organization.	Council resources. Lack of knowledge. Lack of awareness of benefits.

13.3 Conclusions

Methodology

The multiple method approach provides a useful strategy for investigating a complex real world phenomenon (Creswell 2009). Quantitative online interviews are a valuable method of reaching a widespread geographic population, however drawbacks include: a lack of response by certain targeted groups without an interest in the topic; limitations to the number of questions that can be asked; and limitations in pre-coding of responses. In-depth interviews provide invaluable insights and understanding but are time consuming.

Benefits

Recent research and literature on street tree benefits has focused on two main areas: quantifiable environmental benefits (Nowak & Dwyer 2007), and human health and well-being benefits (Tarran 2006). In part this has been an attempt to quantify the services provided by trees, in a language acceptable to engineers and asset managers, and to give trees equal status to other urban infrastructure. It is also an attempt to get beyond the traditional 'aesthetic' rationale for trees. Street trees do provide significant environmental benefits, notably shade, with its multiple local and city wide benefits. However study participants repeatedly raised the fundamental, holistic and less easily quantified benefit of trees, that of making cities more attractive, pleasant and welcoming places (a combination of visual character, aesthetics, 'place-making' and human amenity).

Issues, constraints and threats

The key physical issue is infrastructure conflicts, damaging to both trees and infrastructure (Costello & Jones 2003). Negative community attitudes to trees are also an issue in residential areas. The main physical constraint on tree planting is lack of space, above and below ground (Urban 1992). Water restrictions are also an increasing constraint (Connellan 2008a). The main non-physical constraint is Council resources, including staff resources as well as funding. The main threat is the nature of urban development, both infill development and new subdivisions. Water restrictions are also an emerging threat.

Best practices

There is no one 'silver bullet' best practice, but rather a combination of factors and 'getting the basics right' (Harris *et al.* 2004). The more technical innovations are best suited to city centres where tree planting in the most hostile urban environments is mandatory. Approaches to streetscape design include attempts to increase planting space by measures such as footpath widening and planting in the parking lane. There are also efforts to increase rooting volumes below ground, with enlarged tree pits in suburban settings, and the use of more costly technical solutions in city centres, including tree root trenches, structural soils, suspended pavements, and most recently structural root cell systems (Urban 2008). Water management is an increasing concern, especially the survival of mature trees, with the adoption of strategies including water conservation practices and alternative water sources (Connellan 2008b).

Adoption of WSUD practices varies widely and is influenced by climatic regime and local water quality issues. Many tree managers would like to explore such practices and see WSUD as an important element in sustaining the future urban forest. Management of hardscape conflicts is probably the number one concern for tree managers, and service constraints above and below ground are a major (and increasing) constraint to tree planting. Solutions are often tree based and detrimental to the urban forest. Arborists prefer the improved design and construction of infrastructure so that both trees and infrastructure can coexist. However service relocation or redesign is a very costly exercise. Tree species selection remains one of the main management tools. Tree species selection relies heavily on the use of proven species, often leading to a lack of species diversity. A key concern is that of matching trees and sites, especially in terms of size, but avoiding the risk-averse strategy of planting only small stature trees. Emerging issues of drought, water restrictions and climate change will influence future species selections. Barriers to the adoption of improved practices relate mainly to organizational practices. The two main concerns are lack of resources and lack of knowledge.

Model for Tree Sensitive Urban Design (TSUD)

The draft Model for Tree Sensitive Urban Design provides a useful tool for the more sustainable planting and management of urban trees, to maximize the net benefits delivered by the urban forest. The Model will provide an alternative to current engineering standards which fail to incorporate the biological requirements of trees. Key objectives include growing healthier, longer lived trees and reducing infrastructure conflicts. These can be achieved through a combination of physical (structural) and organizational (non-structural) best management practices. The Model for Tree Sensitive Urban Design can be incorporated in planning strategies by State and local government authorities.

New Knowledge Learnt

The thesis contributes to the existing body of knowledge by making new linkages between existing areas of research and disciplines, such as that between arboriculture and Water Sensitive Urban Design, and by reviewing existing knowledge through a landscape architecture and urban design perspective. A new Model for Tree Sensitive Urban Design is developed which synthesizes this research for use by a range of practitioners. New knowledge has also been developed in terms of best practices for urban tree planting, based on detailed qualitative and quantitative studies of the attitudes and practices of a wide range of street tree managers. This includes an understanding of the essential role of trees in capital city centres and practices for tree planting in the most hostile city environments. The National Practitioner Study provided a new picture of the perceptions and attitudes of tree managers throughout Australia, including perceived street tree benefits, issues, constraints and threats. It also provided a valuable 'snapshot' of the uptake of a range of 'best practices', including an emphasis on sound basic practices with limited uptake of more recent technical innovations. The Metropolitan Adelaide Study, using qualitative research techniques, investigated these topics in greater depth and provided a detailed picture of attitudes and practices for the whole of the Adelaide area. Once again there was an emphasis on the adoption of sound basic practices. The findings emerging from the different components of the thesis research can be summarized as follows. Street trees provide a wide range of environmental benefits, but also play a less easily quantified role in urban amenity and place making. Key street tree issues concern infrastructure conflicts and tree health, but also community issues of negative perceptions of trees and liability/risk management. The main constraint on urban tree planting is lack of space, and from an organizational viewpoint, lack of resources. The main threats to the urban forest are those largely external to tree management organizations, including patterns of urban development and the role of service providers and other authorities. Best practices adopted by tree managers tend to focus on sound basic practices rather than more technical innovations. Limitations on the adoption of best practices relate to organizational factors, a key consideration being the need to educate all stakeholders on the requirements of urban trees and the many benefits delivered by the urban forest.

13.4 Future research questions

In undertaking the study, a number of topics have been identified for future research, which goes beyond the scope of the current thesis.

Water

Lack of water, due to drought, water restrictions and climate change is be impacting on the urban forest in Australian cities (Connellan 2008a). Urban trees are increasingly suffering from a lack of water to sustain growth, despite the presence of a stormwater runoff flowing off surrounding impervious surfaces and along the adjacent gutter. How can this potential alternative water source be redirected to urban street trees? A number of practitioners have attempted to address this issue; for example by stormwater diversion to tree pits (Lawry 2008) or the use of porous paving (Beecham 2003). However there is a need to develop best management practices which satisfy the needs of arborists, civil engineers and water management authorities. Different practices may need to be adopted in different parts of Australia suited to local climatic regimes (Beecham 2009).

Climate change adaptation

Urban trees can play a role in climate change mitigation through carbon sequestration and storage (Moore 2006). A more significant role, however, may be in adapting cities to the effects of climate change, including increased temperature, decreased rainfall, and more extreme weather events

(Thom *et al.* 2009). Urban trees can play a significant role in each of these areas, especially in the reduction of the urban heat island effect. These benefits need to be identified in an Australian context. Strategies also need to be developed to manage potential conflicts between climate change mitigation and adaptation strategies, such as urban densification and water conservation.

Urban development

One of the main threats to urban trees, identified in this study, was that of urban development, including both the nature of urban infill and the design of new subdivisions. Loss of existing tree cover, and of opportunities for future tree planting, especially large trees, may in fact be encouraged by current planning policies and development control procedures (Hall 2008). The issue needs to be addressed at the State (policy) as well as the local government (development control) level. New urban form typologies should be explored which combine urban greening, and space for large trees, with urban densification.

Tree literacy

A key issue identified in the study is the lack of 'tree literacy' (knowledge of the basic requirements of trees) by the different disciplines involved in the streetscape planning and design process (Urban 2008). This includes engineers, urban planners and asset managers, and even some landscape architects. The findings of this thesis should be incorporated in a 'user friendly' document accessible to such parties. In addition, the requirements of trees should be incorporated in appropriate standards and guidelines for use by local authorities. These should also include information on the benefits and 'green infrastructure' role of trees, which also need to be communicated to strategic policy makers, elected members, and the wider community.

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15 Appendices

15.1 Appendix A

Appendix A comprises supporting information for the National Practitioner Survey presented in Chapter10.

15.1.1 Appendix A1: Sample survey questionnaire

The following section comprises the online survey questionnaire formulated using *Survey Monkey* software.

THE UNIVERSITY OF ADELAIDE AUSTRALIA

treenet

Exit this survey >>

TREE LITERATE DESIGN SURVEY

1. General Information

The intention of this section is to gain an understanding of your work role and area of expertise.The survey and it's results are confidential, however it would be appreciated if you could provide some details on yourself and your organisation.

1. Your details.

Your name (optional)

Your position

Name of organisation

State or postcode

2. What part of your Council is primarly responsible for street trees?

3. What is your primary qualification or discipline?

- Arboriculture
- Horticulture
- Engineering
- Landscape architecture
- Urban planning
- None
- Other (pease specify below)

4. How would you describe your main area of work?

- Tree planting/establishment
- Tree/urban forest management
- Strategic planning
- Landscape design
- Other (please specify below)

5. Do you also provide a consultation service on urban trees to other persons or organisations?

- Yes
- No

6. What is your Council's responsibility for the different stages in the street tree planting process?

	By Council	Outsourced/subcontracted
Streetscape design		
Tree planting		
Tree establishment		
Tree maintenance		

Other (please specify below)

Next >>

THE UNIVERSITY OF ADELAIDE AUSTRALIA

treenet

Exit this survey >>

TREE LITERATE DESIGN SURVEY

2. Attitudes to Street Trees

The intention of this section is to explore your attitudes to street trees and their role in the city.Please tick the box that best describes your opinion.1=Disagree strongly, 2=Disagree, 3=Uncertain, 4= Agree, 5=Agree strongly.

7. How do you rate each of the following possible benefits of street trees, from least (1) to most (5).

	1	2	3	4	5
Environmental					
Ecological					
Pedestrian amenity					
Visual/aesthetic					
Economic					
Social/psychological					

Other(please specify below)

8. How do you rate each of the following possible issues or problems involving street trees, from least (1) to most (5)?

	1	2	3	4	5
Poor tree health					
Reduced tree longevity					
Infrastructure damage					
Street tree nuisance					
Liability/risk					
Capital costs					
Maintenance costs					

Other (please specify below)

9. How do you rate each of the following possible constraints on the successful establishment of trees in city streets, from least (1) to most (5)?

	1	2	3	4	5
Space requirements					
Soil environment					
Harsh urban climate					
Vandalism and damage					
Planting and establishment practices					
Maintenance practices					
Water availability					
Species choice					
Species availability					

Other (please specify below)

10. How do you rate each of the following possible threats to street tree planting in your city, from least (1) to most (5)?

	1	2	3	4	5
Policies of electrical service authorities					
Policies of underground service authorities					
Policies of traffic management authorities					

Planning and development policies

Public liability-damages & injury

Cost/funding

Restrictions on water use

Community attitudes

Tree health

Lack of political support

Lack of knowledge by others

Other (please specify below)

11. How do you consider the following Council issues are rated by the community, from least (1) to most (5)?

	1	2	3	4	5
Rates					
Parks and open space					
Community services					
Street trees					
Rubbish collection					
Roads and services					

Other (please specify below)

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THE UNIVERSITY OF ADELAIDE AUSTRALIA

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TREE LITERATE DESIGN SURVEY

3. Tree Literate Design Practices

The intention of this section is to gain an understanding of your knowledge and experience with a range of current and emerging "best practices" in street tree planting and streetscape design. Please tick the box which best describes your Council's use of the following practices.

12. What is your Council's use of the following streetscape design practices?

	Don't practice	Do practice	Intend to practice
Footpath widening			
Traffic lane/width reduction			
Service relocation to accommodate trees			
Planting in parking lane			
Median planting			
Increased planting site size			
Use of shade alternatives to trees			
Grove or cluster planting			
Alternatives to traditional avenue design			

Other (please specify below)

13. What is your Council's use of the following tree pit design practices?

	Don't practice	Do practice	Intend to practice
Increased tree pit volumes			
Design based on arboricultural principles			

Continuous tree root trenches

Structural soils

Suspended pavements

Containerised trees-above ground

Containerised trees-in ground

Other (please specify below)

14. What is your Council's use of the following infrastructure design practices?

	Don't practice	Do practice	Intend to practice
Separation of tree/hardscape			
Root barriers			
Root baiting			
Strengthened pavements			
Flexible pavements			
Relocation of services			
Undergrounding of power			
Redesign of services to accommodate trees			
Aerial cable bundling			

Other (please describe below)

15. What is your Council's use of the following street tree water management practices?

	Don't practice	Do practice	Intend to practice
Increased pervious			

surfaces
Passive watering with stormwater runoff
Rain gardens/bioretention basins
Bioretention tree pits
Underground storage and reuse
Subsurface "cells"

Other (please specify below)

16. What is your Council's use of the following tree species selection practices/criteria?

	Don't practice	Do practice	Intend to practice
Location/country of origin			
Plant fewer larger trees			
Plant more smaller trees			
Availability and cost			
Attractive flowers or foliage			
Rapid growth			
Longevity			
Changing climate			
Ecological criteria			
Drought tolerance			
Consultation with community			
Consultation with landscape architects/others			
Replace with existing proven species			
Opportunity to trial "new" species			

Recommendations by utility agencies

Other (please specify below)

17. Do you have any additional comments?

18. Prior to this survey, had you heard of TREENET?

Yes

No

19. Thank you for participating in this survey.The survey is confidential, however please provide your contact details if you wish to receive a copy of the final survey report.

Name

Email

Address

<< Prev Done >>

15.1.2 Appendix A2: Survey invitations

The following section presents sample online survey invitations with survey links embedded in emails or websites.

SAMPLE ONLINE INVITATION

I am currently undertaking a PhD at the University of Adelaide School of Architecture, Landscape Architecture and Urban Design, which includes an online survey about Urban Trees. The survey, developed with TREENET, is aimed at identifying better ways of designing urban areas to accommodate the needs of street trees, resulting in healthier, longer lived trees and reduced infrastructure conflicts.

If you have not done so already, it would be appreciated if you could complete the survey at the web-link below, and also forward it to any others at Council involved in street tree planting or streetscape planning and design.

STREET TREE SURVEY

With the challenges of climate change, there is an increasing acceptance of the many benefits of urban trees. In this context we also need to better understand the problems facing the successful establishment of urban trees and the "best practices" which can be adopted.

The purpose of this online survey is to gain a better understanding of Local Government attitudes and practices, Australia wide.

It would very much appreciated if could take the time to complete the online survey: click on the link below to go to the survey.

http://www.surveymonkey.com/s.aspx?sm=obEgCLLYnW_2btiZv9bZUwRw_3d_3d

Your response will remain confidential. A summary of responses will also be forwarded to you upon compilation. Please contact Martin Ely at martin.ely@adelaide.edu.au or on 0407809984 if you have any queries or comments on the survey.

Thank you for your help.

Martin Ely
School of Architecture, Landscape Architecture and Urban Design
The University of Adelaide
North Terrace, Adelaide, AUSTRALIA 5005
Phone : (08) 8303 4818
Mobile: 0407 809 984
e-mail: martin.ely@adelaide.edu.au

AILA Newsletter

A Special Survey: Local Government and Urban Trees

The National Office is assisting Martin Ely AILA, undertaking a PhD at the University of Adelaide, with an online survey about Urban Trees.

The survey is aimed at identifying better ways of designing urban areas to better accommodate the needs of street trees, resulting in healthier, longer lived trees and reduced infrastructure conflicts.

The purpose of this online survey is to gain a better understanding of Local Government attitudes and practices, Australia wide.

Do you work in local council? and/or could pass this onto someone who does?

We would very much appreciate it if AILA members in local council could take the time to complete the online survey:

http://www.aila.org.au/news/2008-news/treesurvey.htm

15.1.3 Appendix A3: Response by State

The following section summarizes survey responses by State and type of local authority.

Response by State

Council or authority	**Type**
ACT	
Parks Conservation and Lands	Govt.
	1
New South Wales	
Albury	C
Ballina	A
Bankstown	C
Blue Mountains	C
Broken Hill	C
Cabonne	A
Camden	A
Canada Bay	A
Clarence Valley	A
Coffs Harbour	C
Gosford	C
Goulburn Maulwaree	A
Greater Hume Shire	A
Gunnedah	A
Holryod	C
Hornsby	A
Hunters Hill	A
Hurstville	C
Ku-ring-gai	A
Lake Macquarie	C
Lane Cove	A
Narrabri	A
Narrandera	A
Newcastle	C
North Sydney	C
Orange	A
Parramatta	C
Parkes	A
Randwick	C
Sydney Harbour Foreshore Authority	Authority
Singleton	A
Sydney	C
Wagga Wagga	C
Waverley	A
Wentwoth	A
Wyong	A
	36
orthern Territory	
Darwin	Govt.
DPI	Govt.
	2
Queensland	
Brisbane	C
Caloundra	C
Ipswich	C
Logan	C
Mackay	C
Moreton Bay	Merged
Noosa	S
Pine Rivers	S
Redland	S

South Bank Corporation	Authority
Sunshine Coast	Merged
Townsville	C
	12
South Australia	
Adelaide	C
Adelaide Hills	DC
Alexandrina	DC
Burnside	C
Campbelltown	C
Charles Sturt	C
DTEI	Govt.
Holdfast Bay	SG
Karoonda East Murray	DC
Land Management Corporation	Authority
Marion	C
Mitcham	C
Mount Barker	DC
Murray Bridge	RC
Norwood Payneham St. Peters	C
Onkaparinga	C
Port Adelaide Enfield	C
Playford	C
Port Pirie City and Districts	M
Prospect	C
Salisbury	C
Unley	C
Victor Harbor	C
West Torrens	C
Whyalla	C
Yorke Peninsula	DC
	26
Tasmania	
Glenorchy	C
Latrobe	M
Launceston	C
	3
Victoria	
Ararat	RC
Banyule	C
Bayside	C
Boroondara	C
Brimbank	C
Buloke	S
Casy	C
Colac Otway	S
Corangamite	S
Frankston	C
Greater Bendigo	C
Greater Geelong	C
Greater Shepparton	C
Hobsons Bay	C
Horsham	RC
Knox	C
Latrobe	C
Maribyrnong	C
Maroondah	C
Melbourne	C
Mildura	RC
Mitchell?	S
Monash	C
Moreland	C
Port Phillip	C
Stonnington	C

Swan Hill	RC
VicRoads	Govt.
VicUrban	Authority
Wangaratta	RC
Warrnambool	C
Wellington	S
Whitehorse	C
Yarra	C
Yarra Ranges	S
	35
Western Australia	
Belmont	C
Bunbury	C
Esperance	S
Joondalup	C
Kalgoorlie-Boulder	C
Mandurah	C
Perth	C
South Perth	C
Stirling	C
	9
TOTAL	**124**

LEGEND

NSW	**Qld**
A Area	C City
C City	S Shire
WA	**Tas**
C City	C City
S Shire	M Municipality
Vic	**SA**
C City	C City
RC Rural City	DC District Council
S Shire	M Municipality
	RC Rural City

15.1.4 Appendix A4: Open ended responses

The following section provides a compilation of verbatim open ended responses provided for each survey question. Comments have been coded in terms of key response categories that emerged from the data.

Question 7 Perceived street tree benefits (31 responses)

General

I personally rate all very highly but the environmental, ecological and economic benefits are generally ignored for projects.
Predominantly street trees in inner suburbs.
Too numerous to mention!
There are numerous other positive benefits.
I think street trees confer enormous benefits.

Environmental

Point-of-source water treatment potential in built-up streets.
Reduced Heat Island Effect - Climatic benefit depends on the species.
some trees contribute negatively to the environment through leaf fall, phenolics, invasiveness etc. - need to be local native species biological as it creates shade and prevents skin cancers.

Ecological

I would like to mention that I don't feel enough street trees are planted in regard to their ecological benefit for providing food and habitat for indigenous animals. Many Street Trees proposed by some developers and councils are considered noxious weeds in other states and I also don't like the recent proposal in I think it is "Melbourne 2030".
It states that streets should be planted with single species in order to achieve "grand avenues" or for some similar reason. It is counterproductive to producing streets with biodiversity and a range of food/habitat trees for local wildlife.
Can't always satisfy ecological objective because the system is so disturbed; sometimes we just need trees that can survive.
Ecological - it depends on where that ecology is located.
Only some species have high habitat values.
While I love Australian eucalypts, I'm not sure about them as street trees; deciduous less risky?
Street trees can be a way of educating residents about endemic species and improve awareness and appreciation of endemic species.

Amenity

Farmers like to come into a green cool environment to feel better than they do on drought stricken lands.
Providing shade over parked cars is important in our hot climate.
Sun protection is a big priority as we have the highest rate of skin cancers in the country.
Improve microclimate.

Shade

Physical shade / shelter (micro environmental- i.e. alternative for shade sails).
I rate street trees very highly as an investment in shade, comfort, beauty and contribution to amenity of the city.

Economic

Trees equal amenity equals property value equals suburb amenity equals higher suburb desirability equals higher prices equals higher investment in amenic infrastructure like trees (on private land).
It's a pity Councils don't seek to enhance suburb amenity by accepting that higher infrastructure repair costs from planting more larger trees (not under powerlines) is the price for higher suburb amenity equals more rate return to pay for higher costs. Imagine a world with big trees everywhere in suburbia and no or minor infrastructure repair costs. Underground power lines NOW. Consumers will contribute to the enhancement of their public amenic environment, if they get a return from higher property prices. They did it in Perth and doubled the population in 20 years without any tree protection legislation.

Social/psychological

Traffic Safety - slow traffic speeds.
Can have positive effects on vehicle traffic calming.
Physical wellbeing (e.g. some relates to psych; economic) but more to it ... like contribution to preventive health; community well being etc. (rate at 5).

Cultural/heritage
Heritage values Tree size.
Heritage value 5.
Some remnant trees have heritage significance (e.g. Aboriginal Scar trees). Historical/memorial (links to psychological) (rate at 4) Cultural-e.g. Avenue of Honour.
Other values include heritage/character of an area can be determined by type, size etc of verge trees.

Other benefits
Food.

Issues
Agree strongly on all the above being subject to; the fundamentals of 'right tree in right place' appropriate maintenance practices suitably applied and; is sustainable or; has sustainability planning woven into regime....stakeholders support typically required to achieve success.
My experience has been that the general population actually hate trees with a passion as they drop leaves etc and people have to clean up the mess.
I believe in street trees. I grew up in Kuringai Municipality in urban Sydney, - very conscious of street trees. Here, there is nervousness about risk I think.
It is distressing that so many residents are now allowed to have the tree on their verge removed at whim.

Question 8 Perceived street tree issues (27 responses)

General
All of these problems can be minimized if the correct planning, design and tree selection decisions are made prior to the planting and construction work being done. Problems are typical of established trees in older streets.
All of the above depend on the age and type of tree, width of street, sidewalk etc.

Tree health/longevity
Difficult to answer. The LGA is relatively young, so longevity has not yet become an issue. Tree health generally ok (sandy soils, many open verges, not highly polluted.
Aging tree population combined with drought and salt is causing a massive decline in tree population.

Infrastructure conflicts
Being an inner city council consisting predominantly of 19th century infrastructure and the demand for greening causes conflict.

Below ground services
Existing utility regulations for sewer and water keep us from planting many street trees in Adelaide.

Powerlines
Powerline clearance impinges greatly on the benefits of street trees.

Buildings
Infrastructure in Yarra is old and most houses are Victorian era built with little or no foundations on very reactive clay. Doesn't mix with trees planted in the past-Planes, Melaleucas etc.

Compaction
Infrastructure damage i.e. compaction of rooted soils/ root damage and the like, during upgrading/ land development constructions etc; are widely known to be the leading causal agents in decline of urban trees. The components of tree health, reduced longevity, capital/ other costs would be typically brought about by the tree damages or constraints handed out at some previous time; if a street tree was deemed a nuisance; then perhaps the planners or managers of that tree should be taking a closer look at what they've planted and maintained respectively; before handing out 'nuisance' notices!! Damage to trees that causes most of the fatalities is root damage from other government services, road widening by Council operations and redevelopment of property in the older areas.
Poor growth rates due to soil compaction (i.e. a bonsai effect) rates as a significant issue at VicRoads.

Risk
Tree risk is a real issue and the reality is that the probability of risk (of tree) eventuating is so minute compared to other 'everyday exposures to household and work-place risk' however; I'm sure the vast majority of asset managers whether assets be trees or other; would consider and act upon minimizing any risk surrounding; a sound method for measuring and managing tree risk may be provided by tree appraisers separately yet certainly; should form component of any worthwhile tree management program.

Nuisance
Street tree "nuisance" problem is largely dealt with by application of consistent policies:
I would add to this list -views screening properties- (particularly in coastal and river foreshore areas, or any long attractive views, where the general public does not support trees).
Not sure what street tree nuisance is and how it differs from infrastructure damage. Does it relate to autumn leaves and messy fruits?

Urban development
Lack of balance re trees and development (due lack of understanding and conflict with short term returns) would rate a 5.
Also developers can be very difficult on matters of species selection with developers seeking to achieve a certain 'image' with the street trees that may not be compatible with the environment and conditions (e.g. deciduous European trees which cause problems with seed dispersal, leaf drop and root penetration)
And the greatest threat (and potential blessing) is man's influence and urbanization.

Costs
Rate return for street tree infrastructure investment. Councils want ongoing income for less outlay so we get smaller trees, less amenity, reductions in suburb values (or less capital appreciation comparative to leafier suburbs). I don't see any positive ideas or reasonable changes to suburban infrastructure provision. Just same old crap. It almost makes me want to work for Council as an employee. Perish the thought! I make a living assisting people/developers to get better outcomes from belligerent Council burocracy (as long as they listen to me and agree to do what I tell them).
Luckily there is sufficient budget to cover costs required to manage trees to a professional standard.
Capital costs met under budgets.

Management, maintenance
Proactive tree maintenance has never occurred in this town.
Trees are not the issue; their poor management is of primary concern.
Maintenance should be done by a qualified arboriculturist. This doesn't happen. Rather let's say the energy authority comes along, has its "policy" prunes accordingly, leaves a tree unbalanced, prey to disease and insects etc. So a problem created.
Proper street tree planning would require a co-ordinated approach. Doesn't happen here.
Our council has a cyclic street tree replacement/infill program which caters for replacement of many aged street trees or trees which should be replaced due to declining health or aesthetics.
Lack of quality stock limited knowledge of trees / urban landscape by contractors / developers Poor post establishment practices Poor understanding of trees / soil relationships.

Other
Climate/water
Climate change would rate a 5.
High water use to maintain deciduous trees.

Public perceptions
Unfortunately the true value of trees is not relayed to the community.
Poor public perception of street trees is a major issue for us, i.e. people fear trees will damage property & create nuisance.
Lack of awareness of tree benefits amongst the community would rate a 5.
Another problem is community perception of 'danger' versus the other benefits of large street trees.
The question is not formulated clearly. I am guessing its intention and I am confirming that all the above contribute to the common, often very negative, attitude towards urban trees.

Car parking
Loss of car parking.
Vandalism
Vandalism (especially when first planted).

Tree protection
Insufficient protection of trees, require greater recognition and weight under the law.

Space
Not enough room to grow canopy trees-too many competing demands and conflicting interests.

Biodiversity
Planting of environmental weed species; reduced biodiversity and gene pool pollution of indigenous species; Biggest problem is inappropriate tree plantings and failure to maintain natural trees - replace them with exotic species which cause all the problems above.

Question 9 Perceived constraints on street tree establishment (28 responses)

General
Again answers to this section depend on type of tree chosen, width of street, and most importantly the degree of climate change that is occurring quickly, (i.e. water and rainfall regimes.)

Space
Our footpath specifications for new infrastructure allow space for trees. We have 'set-outs' that require trees to be certain distances from utilities etc.
Maintenance and space critical factors.

Species choice
It's selecting the right species for the area to take on all of obstacles it has to grow in.
Species selection in Bendigo rarely involves endemic species; suitability is paramount in health/longevity of trees.
Climate, space and water availability problems can be minimized by selecting the most appropriate species.
Things you have control over are not an issue i.e. species selection for the right location. Changing clay soils that waterlog even in summer is difficult.
As old tree stock is removed we assess each planting area to ensure that replacement species are suitable to the area.

Soils
Clay soils make establishment of trees difficult. Can be very dry to saturated.
Coastal Plains and salt zones combined are very difficult for street tree options and establishment.
Shallow soils and sandstone geology mean that there are many failures when traditional 600mm square pits are dug. There is a lack of recognition of the need to invest in tree pit infrastructure.

Water
Water an issue only for establishment phase, with time for truck to travel from site to site.
Poor representation of examples (at least currently) promoting creative stormwater designs where trees are sequestrating nutrients from stormwater.
Lack of firm regulations encouraging using water sensitive urban design (advice notes on development approvals don't have enough legal weight); should this come from state governments?

Management

Budget
Maintenance Budget 1.

Political support
Political unwillingness.

Understanding, knowledge
Actual understanding.
Inadequate arboricultural knowledge/understanding.

Innovation

Lack of Council staff progressive /proactive thinking. Are they just complacent or are they just too tired to bother? Are they paid not to think or do political forces and management discourage enthusiasm and creativity.

Policies

Inadequate policy framework – 5.
The biggest vandal is the council, which is obsessed with public liability and committed to inappropriate species.
Lack of urban trees management and replacement plans.
Lack of strong policies protecting street/verge trees.

Maintenance

Maintenance and space critical factors.

Stock/availability

Quality of trees planted - especially rootstock.
The City of Greater Bendigo has an in-house plant nursery where we can propagate and grow-on trees. There is space there for 1000 advanced trees. The greatest% of plants propagated are native, many others are grown on for purchased tubes etc.
Supply of species quantities, even species that nurseries supply sell out quickly in March / April or end up with inferior stoc.k
Availability of sizes (most Australian trees establish better, live longer in the given location when planted as a small seedling; push to produce advanced stock reduces the species choice).
Species availability is not a problem if several options are available for selection. Council also operates a Community Nursery which can provide many locally endemic species in bulk amounts.

Other

Community attitudes

A major constraint is attitude of ratepayers to the variety of tree on their verge (problem in city is strong dislike to existing Qld. Box trees). Some residents just don't want a tree; Council is unwilling to over-rule this.

Urban development

Urban consolidation through subdivision of existing house lots is reducing the existing stock as well as the opportunities for new planting. With the smaller lot sizes street trees are becoming more important and are the only area left where good sized trees can be planted other than parks. With the trend to reduce road widths, include cycle ways and include the services within the footway, tree choice is becoming more restricted.
Tree planting could be built in at the subdivision stage but this doesn't seem to happen.
Establishment and maintenance are the responsibility of the developer in accordance with conditions of consent until an acceptable time frame e.g. one year from planting.

Other

The items under 9 above 'successful establishment' for us here in Singapore refers to a time period of 2-3mths; in Australia this may be 1-2yrs subject to regional climate / conditions etc. If an establishing tree were to find constraint influenced by soil space in this early period, it could never have been expected to sustain beyond establishment in the first instance; planting medium qualities and volumes adequacy can be issue to succeed establishment; this responsibility usually rests with planting specified and/or contractor; similarly for maintenance. A suitably selected tree species for location/ conditions, pre-grown by professional grower with its end use in mind and planted & maintained properly succeed.

Infrastructure

Infrastructure constraints e.g. overhead power lines.
Include destructive treatments by utilities companies -above and below ground - as vandalism &; damage!).
Interaction with infrastructure below ground needs to be well managed.
Another issue is the conflict with vehicles, particularly waste collection and the requirements of electricit.y providers to keep trees clear of wires in areas without underground power have resulted in 'butchering' of trees in some cases. Recent adoption of Australian Standards has improved the manner of pruning in most areas.

Question 10 Perceived threats to street tree planting (20 responses)

Service authorities

Power being undergrounded, authorities use horizontal boring, little damage incurred
What we want and we get are two different things. We want leafy suburbs and high amenic enjoyment and we get shrub plantings under power lines, noisy unsafe roads where they remove street trees because someone

pranged into one which Council never replaced. Get rid of power poles which kill a lot more people. Take on ETSA and Councils today! ...well maybe tomorrow.
Policies of utility services can be designed for because the standards and construction methods do not vary and can be accommodated.
I'd phrase my threats a little clear zone requirements for road safety combined with little or no expenditure on safety barriers (5) electrical line clearance requirements combined with no expenditure on undergrounding of power lines (5) These are the 2 most significant threats to tree planting on new arterial roads across Victoria. Note the combination of a legal or policy requirement is a problem when capital is not available to manage that requirement in a way that permits.

Knowledge

Lack of balance in compromises between the professions ... e.g. comment from a young graduate civil engineer "horticulture is what you do when we've finished the real work."
Managers with no arboricultural expertise.
Traffic authorities.
I'd phrase my threats a little clear zone requirements for road safety combined with little or no expenditure on safety barriers (5) electrical line clearance requirements combined with no expenditure on undergrounding of power lines (5) These are the 2 most significant threats to tree planting on new arterial roads across Victoria. Note the combination of a legal or policy requirement is a problem when capital is not available to manage that requirement in a way that permits.

Funding

Biggest issue is lack of funding for a street tree planting program.
The attitudes of key staff in the organization means there is a lack of political support.
Planning and development.
Planning and development policies need to be improved to increase the importance of designing for street trees and clearly notifying developers up front of the requirements to provide street trees and the design specifications required.

Community attitudes

Societal values and the culture of egoism and rampant consumerism within western society.
Two comments. I love trees but everyone thinks they are experts on trees.
Public acceptance of street trees can be negative in some areas with certain members of the public preferring a green lawn and no tree as it interferes with parking.
Community attitude is the biggest threat in relation to trees. It is often the 'NIMBY' syndrome, "I Love Trees - just don't plant them outside my house! People complain about leave/berries/flowers/caterpillars/bees/nuts etc and it takes a hard line from our politicians to say the tree stays. There is a need to keep the community informed of how important trees are to the environment and also the aesthetic/economic realities of trees.
Community attitudes would vary greatly in this municipality from those who don't seem to mind living with vertical and horizontal concrete as their environment to their opposite; the latter would welcome trees and want those trees that are here retained. We seem to be in the older age groups.
The majority of the public think everyone loves trees; it is not the case or yes but not in front of my house. The old adage "I love trees, but!"
Planting generally supported politically but opposed by individual residents.

Water, climate

No water restrictions in the township area.

Climate change

We have storm water retention for tree watering. Tree health is current as we have no depth in soil moisture for the past 3+ years.

Other

Vandalism

Vandalism is a big threat in the City.
Poisoning and midnight pruning of park trees and street trees for "improved" sea views is rife. Vandalism is also high in certain areas.

Management

Lack of clear policy directions and inconsistent approach and applications where there is policy.

Species selection

I believe some of the issues above can be overcome with prudent species selection.

Other

None of the above; not relevant to Singapore; urban greenery generation and conservation supported & instigated through government planning policy and....dedicated arborists too!

Question 12 Streetscape design practices (30 responses)

General

Response as consultant observing emerging trends.
Mostly resisted by designers/engineers.
On a project basis - e.g. Lochiel Park, Playford, Northgate, Golden Grove.
Councils employ consultants to produce quality design and generally only offer guidance/comment on the finished product. Council produces basic urban design responses to minor engineered road repairs and don't design outside the the square. It's not their business. They don't seek areas for large tree plantings in new housing schemes. Everyone calls them environmental marvels (like Mawson Lakes) but what a load of underwhelming hype all round.
Council is preparing a new Development control plan which is intended to contain guidelines and specifications for street tree planting which will hopefully include a variety of instructions and measures as listed above to improve long term maintenance.
We strive to implement all of the above. It can be difficult persuading other internal depts. E.g. typically, asphalt roads take priority over 'green stuff'. But we keep trying and make small victories.
Tree planting such as suggested simply NOT on the agenda..... If only.
The council has not thought about any of these things.
State Highway authority (NSW Roads and Traffic Authority) practice some of the above better practices in Highway upgrading work. Council invests very little in landscaping outside Parks and shopping centres.

Medians

Median planting- only if there is 4m or more median width a root control barrier to protect the road and enough soil volume to support the selected tree species at maturity.
Answers for VicRoads. Additional notes: Median planting - yes, but not trees. Alternatives to traditional avenue design - yes we do practice the alternative of no planting!!!
Trees used to be planted in central medians but in response to new guidelines from the state govt. road authority this will no longer occur.

Space

Council is working with the Growth Centre's Commission to ensure that there is room for street trees in its release areas. The State Government has mandated road widths and left little room for trees however we will ensure there is some room left!
Very little space to plant trees except in parking bays, no medians and narrow footpaths in narrow roads.
Footpaths are a standard 1.5 m wide unless they are shared paths (hike/bike) in which case they are 2.5 m.
We got big old roads here.
Nature strip?

Footpath widening

Kerb extensions in narrow streets and shopping precincts.
Shade structures.
Council has used umbrella structures in some town centre sites, where funding permits. There has been resistance by the engineers to use trees in parking lanes unless part of footpath widening/blister proposals.

Parking lane

Planting in parking lane- this has been done in the past but we don't like it and are no longer approving this type of design.
Informal planting.
Informal planting on streets is associated with Water Sensitive Urban Design treatments otherwise a formal avenue approach is used.

Other

Services

Fund for aerial bundle cabling in nominated streets - less costly than undergrounding
Relocation is minimal.
Interested in changing to ABC cable to prevent 'V' pruning of tree canopies. While electricity companies want council to ensure services a clear will not help by subsidizing ABC cable installation.

WSUD
Behind kerb SW cells for street tree irrigation has been investigated. Currently, Caloundra has never had any water restrictions as our dam averages 85% capacity. This will change shortly when Brisbane connects to our dam. This will change our water use structure considerably.
WSUD measures.
Water sensitive urban design with street tree planting.

Species selection
Drought tolerant plants where suitable. The aim is to plant a tree of an appropriate type in the right location.

Question 13 Tree pit design practices (35 responses)

Extent of adoption
Want to/should practice.
Those "do practice"; items are only in very small numbers, in certain areas of the CBD only. City wide, almost non existent.
Mostly resisted by designers/engineers.
Still pretty standard planting techniques.
All of the above are in the experimental stage.s
Council engineers have primary control over streetscape works but have not supported innovative use of structural soils, tree planting in parking lanes or relocation of services due to funding constraints.

Volumes
Limited application of increased tree pit volumes in major projects but not minor street tree planting projects.

Arboricultural principles
Council follows the planting specification recommended by Craul (1992).

Trenches
Continuous trenches and structural soils occasionally.
Continuous trenches often in rural road circumstances.
We have trialed with continuous tree root trenches on a reserve constructed by a developer within our council area. Generally this is difficult to attempt in the streetscape due to extensive service present.

Structural soils
Structural soils have been used but not in association with suspended pavements.
Feedback from landscape contractors + soil suppliers is that there is a lot of ignorance regarding what structural soils actually are and how they should best be installed. It is also apparently difficult and can be costly to supply structural soils to projects outside of the major Metropolitan areas.
Structural soils only used in urban environments where funding permits sometimes use.
Structural soils- has been used this in clay soil by others, did not work at all, are considering for sandy soil.

Containerized
Portrush Road Median has containerized plantings.
Comments relate to the streets within South Bank not BCC In relation to the last two points we do have some podium type tree planting at ground level with very generous root zones.
Above ground containers-not often.

Other
Subsurface cells
Arborgreen root cells as an alternative to structural soils.

Soil improvement
Mass ripping and mulching, with a view to using compost as well. In many of our cases, our limitations don't involve a small available root volume. As long as we can get air into the soil (and water) we should be right. Our specification also requires cultivation, but we rarely see it undertaken.

Root barriers

Root barriers are still practiced, although the arboricultural seminars are teaching us that the use of blue metal/gravel instead of yellow sand under pavement within the tree drip line should be used to discourage roots from shallow growth under the pavemen.t
Council requires root barriers rather than containerized trees in the ground.
Use of root control structures on planting.
Council are now using Root directors supplied from Woodchuck Landscape Systems in Mount Barker.

WSUD
Implemented Water sensitive urban design effectively container growing.

Question 14 Infrastructure design practices (32 responses)

Extent of adoption.
As above, very small quantity of "do practice" items.
Council engineers have primary control over streetscape works but have not supported innovative use of structural soils, tree planting in parking lanes or relocation of services due to funding constraints
We try all of the above. Depends on project and budget and site.
Unfortunately the infrastructure unit (engineers) work separately from tree design team. Difficult to change long held beliefs. However, are starting to get them on board with WSUD.
No-one bothers with this stuff in my Council as this is called thinking outside the managers parameters. Remember, incompetency is promoted the hell away from good blokes.

Root barriers
Root barriers used as reactive not proactive, strengthened pavements, relocation/redesign of services sometimes.
We only occasionally use root barriers. We have much research inside VR on root barriers, but there are varying opinions within regarding whether they work or whether they are useful.

Undergrounding power
Western Power runs a program of retrofitting nominated suburbs with underground power lines
Undergound power and bundling are cost prohibitive at this stage.
Street light wire removal is also cheap, funded in partnership with our electricity distributor and gains considerable additional tree growth space under other overhead conductors.
Much of the council area is in the urban growth corridor and all new services are undergrounded.
Undergrounding existing overhead power lines is too cost prohibitive for council.
We encourage undergrounding of power in new developments, however the idea is most often rejected due to high costs.
Undergrounding performed for heritage not tree purposes. Undergrounding of power in new developments
Comments relate to the streets within South Bank not BCC Not sure what is meant by first point Power is already underground - no above ground cables.
Undergrounding-a couple.

Aerial cable bunding.
Cable bundling does not change pruning regulations, so ineffective.
Some aerial cable bundling has occurred - but no ongoing program.
ACB less now.
Aerial bundling is undertaken by the responsible authorities.
Aerial bundling and overhead power lines not within their jurisdiction. Camden Council does not provide electricity services however it does encourage cable bundling in area with above ground services. Council follows the Road Openings Conference standards in relation to service locations within the footway.
ETSA funding needs to increase to support more aerial bundling.
Would like to see aerial bundling practiced but this is the responsibility of the service authority.
Not cost effective to replace i.e. one span e.g. ABC cable can cost $15,000.
Extensive overhead cable bundling due to initial provisions by State when legislation introduced in 1980s, little since.

Service relocation
Working with power company to redesign infrastructure.
Redesign of services &; relocation of services is minimal.
Second last item, service relocation - only where significant ecological or amenity.
Relocation of services prohibited by cost.

Root baiting

Root baiting-?

Question 15 Water management practices (33 responses)

Extent of adoption.
Pervious surfaces and passive watering occasionall.y
Rain gardens, bioregion tree pits?
Only apply WUSD in appropriate locations.
This is the tropics; we get rain events of up to 1m in a week!
City of Perth in the infancy of water management practices!
Limited exploration of these innovations due to budget constraints.
Again, try to do all of the above. Depends on budget, timeframes, etc.
When I say 'intend to practice', it is the sort of intent that will require 5-10 years to change organizational behavior. Council relies on Mother Nature and tree selection for street trees to survive the harsh climate after requiring the developer to maintain the trees during their establishment phase which would include manual watering.
Over the last few years we have ventured into adopting some of these practices I have been trying to implement WSUD principles in the City of Marion since arriving here after working in Brisbane where I was heavily involved in these practices.
WSUD services outside Council's control.
Development approvals.
Mostly undertaken by Developers.
Development Assessment unit does condition bioretention, biofiltration etc.
When I say we practice some of these, it is primarily by conditioning a DA, we don't have a lot of control over the actual installation.
New developments generally address most of these items as a development requirement.

Passive watering
The passive watering would potentially include bioretention tree pits.

Underground storage
Underground storage not useable from first tests done.

Subsurface cells
Subsurface “cells” are new (in one park) still under the control of the developer, bus yes, it was encouraged by the City and approved by the WA Planning Commission. The adoption of the rest of the water management practices is slow.
“Cells” = aggregate filled trenches.
Storage cells are just coming onto the radar now that water restrictions are imminen.t

Other
Recycled water
We use treated effluent water on the street trees the city plants.
Street Trees are now watered with recycled water at the City of Salisbury.
Use of reclaimed water.
Use recycled water for Parks.
Use of treated effluent.

Soil additives
Use TerraCottem soil condition to reduce watering.

Water trucks
Water Trucks for street plantings.

Wetlands
Development of water catchments as wetlands for water holding and irrigation.

Question 16 Tree species selection practices (31 responses)

General criteria
Visibility-single trunk, amenity to pruning, tree vigor, environmental weeds, flower irritants, not too vigorous roots.

Manageable root systems, weed/invasiveness potential, litter abundance, liability e.g. berries/trip/slip hazards
Indigenous/exotic.
On the use of indigenous species and avoidance of species regarded as potential weeds in locations close to areas of natural vegetation.
More emphasis on native street trees & mixed species for ecological corridors, better biodiversity and food for bats, birds and possums.
Council plants mostly natives originating from coastal communities ranging from Northern New Sales Wales to South East Queensland and North Queensland. And to a lesser extent exotics from a similar geographic range/climate.
Council actively encourages seed collection of endemic species for use on development sites. It works with agencies such as the Mt Annan Botanic Gardens to propagate the seedlings at the cost of the developers of the release areas.

Size
Due to confined spaces use of smaller species.
Trend is to go larger Availability/cost-grow in-house.
Depends on site and response from residence.
The answer above about tree size is this in relation to mature specimen size or installation size.
We plant the largest trees possible for the planting site - hence in many locations there are fewer larger trees, and in other locations there are smaller trees where the utilities cannot be re-designed for the next 15-20 years.
We plant small trees under overhead power lines and larger trees.
Choice of large/small tree is determined given consideration to available footpath width, scale of street and set back of adjoining buildings - no active decision to plant more big or more smaller trees.
Should be plant fewer, larger trees - not fewer larger trees?
Plant indigenous tube stock in WSUD treatments otherwise minimum size street tree is 2.5 m.
While everyone wants large trees to look at no one wants them near their property as they may cause problems, roots, leaves, shadowing etc.
Size location dependant.
Larger or smaller trees-depends on location.
Plant fewer but advanced trees within streetscape/ town centre environments, but within suburban streets we will plant more smaller trees.
Smaller trees-depends on area.

Availability
The main problem we have is the availability of the select few species we are able to use
Consultation with others.
Consultation only occurs with developers who seek to understand what the minimum requirements are to achieve Council approval. So we get new tree plantings into rubble in car parks and compacted verges in new streets. The architects tend to do the urban design (you know real fast with rubber stamps and all botanic names miss-spelt) and tender out the landscaping expertise to a contractor. Landscape architects, who are you kidding!
Consultation with others for major programs.
Believe arborist has better idea than utility services regarding tree selection.
Consultation with others- occasionally.
Utility agencies.
Recommendations by utility agencies - has proven very difficult and limiting in South Australia. To give an example, the largest tree allowed (without specific permission) to be planted around power lines is a Callistemon...
Recommendations by utility agencies depends on the species and its proven record in the area.

Other
Street Tree Policy
We have a street tree planting policy which details species, planting requirements etc
Council has adopted a street tree planting strategy so it not necessary to continually consult the community about species selection.
Tree species is usually dictated by Councillors.

Question 17 Any additional comments (51 responses)

Values, benefits, support

Council take trees in town for granted and put a higher value on sealing road shoulders (over large tree roots) than on carrying best practice or exploring new practices to achieve the same results.
This council has not changed its approach to tree planting for years. Trees are generally treated as a liability. Staff do not appear to be interested, are not qualified and do not pro-actively manage trees.
Street trees will only ever be valued equally among the other resources and structures located in the road reserve if their status as plants is heightened to elevate them to utilities that provide beneficial and monetary worth as other utilities do. For trees such values per tree per species need to be calculated for carbon sequestration, incipient water storage, reduced drainage and drainage infrastructure costs, sociological worth, shade, prolonged pavement life contribution by shading, value as harvestable timber etc. Then as a utility the funding required to maintain the resource over its expected lifespan can be more accurately allocated and the worth of the tree as a utility that is more than aesthetic could be better communicated and their importance better understood by the broader community. At this time more appropriate funding for staff, maintenance and research may be easier to achieve.
Councilor support for trees in general appears to be dwindling due to increasing tree complaints from the community. However, it is also noted that when trees are removed from the community, it is only then that the community is as much for trees, as against.
We have presented to the Councilor's the statistics and triple bottom line benefits of street tree planting, specifically the effects of climate change and amenity. Unfortunately the point was not really accepted. They were more concerned with potential problems and local issues to understand bigger picture
Would love to see more research done regarding the benefits of trees especially relating to human health and other cost benefits.
One of the single biggest issues is that generally people don't appreciate trees, the time, effort and how difficult it is to grow a tree to maturity in the public arena, as stated earlier most people are unhappy with the mess that they create.
Street trees will be the most important trees in our new release areas as lot sizes become smaller and people don't have the room for backyard planting - yes, even in Camden! For this reason, Council continues to explore means of educating its community on the importance of these trees and 'ownership' of the trees by the residents.
Political and public perception of the real benefits are the prime stumbling blocks. Lack of open collaboration with service engineers is the second problem and the lack of can do attitude.
Council attitudes are influenced by policy, staff involved, etc as well as traditions within the area. The approach to landscaping also differs depending on the ecological or amenity values of an area.
Trees are a high priority for us at Ipswich City Council.
Vandalism, theft, and "don't get me wrong I love trees but ..." are the biggest issues. Followed closely by "my house is cracking and the engineer said that tree ...." whilst ignoring the climatic conditions over the past ten years.

Council organization, management

Planting is carried across different sections of Council, and there are a number of different approaches. In new capital works we usually have the luxury of being able to design for and specify our needs to create environments that are a bit 'special', and can therefore use trees that may be larger, and with sub-surface conditions provided for the longer term. Day-to-day tree management practices and decisions relating to street tree planting are usually maintenance and budget driven - and there is never enough money
*Too many to note. Call me on ********** if you wish to discuss further.*
Local area is covered by five different Councils (a rural environment). Procedures are generally behind that of the larger metropolitan centres (behind the times).Generally trees suffer e.g. Catchment Management Authority can override TPO's and VMO's re tree removal. These sort of anomalies are a cause of concern.
Wagga Council is moving forward with changes to their tree management, however budgets restrict works. Working towards proactive management of urban trees as we have started auditing all our city trees with Homewood Consulting Services Vic.
We are currently reviewing our street tree and urban forest practices. The main impediment to implementing good tree practices seems to be the lack of any dedicated person to be a "tree advocate". Until Council creates this position, we will continue with the present ad hoc process of doing what we can when we can. We are making progress though; we are working an Urban Forest Management Plan and reviewing our DCP to make it more tree friendly.
Council has recently engaged an arborist who will provide standards and recommendations on tree maintenance practices.

Budgets

Budgets are tight and there is limited support towards street tree planting programs anywhere. Planting tends to occur in limited scope, mostly in association with major capital infrastructure works, with a very small recurrent tree planting program. A lot of resource is focused on the tree assessment task, a large portion of *which deals with private property. There is limited survey or knowledge of the condition of the tree assets overall.*

Maybe this is the real face of development- South Australian rustbelt style. All talk and hype, little substance. I think the problem is that Councils are reluctant to publicly talk about rate revenue or claim to seek higher rate returns in exchange for higher quality/cost amenic infrastructure such as plentiful large tree establishment and undergrounding of power lines. There are some great potential initiatives (as listed in this survey)available to Council's that would reduce annual operating costs but seemingly there is no incentive to make a leap or even trial into the great unknown of capital expenditure on items that are not roads or drains. Perhaps this a real problem for Council's who can't see the link between amenic expenditure and rate return on investment. Perhaps the problem lies with the people who spin Council under-achievement and the public who have been trained to expect it. I solve development problems with regards trees by engaging these initiatives and Councils love it, but they don't practice it. I would like to see Landscape Design a mandatory requirement of new development within the Development Act in the same manner as significant tree protection has been incorporated. Better outcomes, better quality urban design, guaranteed industry base. You beauty. While we're on that topic, why shouldn't tree planning and planting require development approval?

Maintenance

This survey didn't have reference to the use of trained/skilled/qualified/knowledgeable tree maintenance staff. I believe this is an important part of tree development/establishment/management. We as a council are struggling to find suitably qualified and skilled staff.

Strategies

I would encourage you to read our AILA Award winning Greening Footscray Strategy (see link). The Strategy was developed to respond to the issues of Footscray's urban environment. It first outlines the desired tree 'effect' based on existing strategic positioning, then selects a preferred species that meet the criteria for the effect, meaning the trees can achieve a whole lot of social, economic and environmental goals.
http://www.maribyrnong.vic.gov.au/Page/page.asp?Page_Id=2949&h=0.

We also have several "rules", "laws" and other development standards/requirements which are critical to optimizing positive street tree outcomes/management and minimizing liabilities. E.g. Street Tree Policy Standards for Tree Planting/Establishment; Tree Removal/Community notification; and Tree Valuation: Tree Protection during construction City Plan- Subdivision standard conditions for street tree contributions and Natural Asset Local Law and detailed survey of 10% of estimated street tree population, and other asset data from satellite imagery; stratified random sampling; community attitude surveys etc. and several strategic documents approved by Council- e.g. Subtropical Boulevard Strategy and Neighbourhood Shadeway initiative

New to this Council so not up with past practice. Council just releasing new 'Tree Policy' for public comment, looks promising and will embrace 'best practice'.

Council is currently undertaking an Undesirable tree removal program which incorporates a replanting process of desirable trees and shrubs at new safe distances with root directors. please contact me if you would like some photographs or information.

Innovation

Very difficult to get landscape consultants who are keen to try innovative and sustainable techniques including run off into gardens & tree pits, and who will focus on native species selection - the nursery industry has been very slow to develop and market native species for urban and street tree use. Street trees could make huge improvements to roads, particularly around the edges of towns - often "suburbs" or peripheries suffer from poor quality landscapes which could easily accommodate large trees alongside roads

As we use qualified consultants we think we get the current best practice advice - consultants have trouble designing to a price and delivering on time.

Urban development

The most important aspect is getting trees back into the residential areas where they have been lost through increasing densities. As areas are not available on private land due to this intensive redevelopment, the only alternative is within the road reserves. This also has many benefits in improving the environment we live in and also making it a better place.

Many Council's UNDERESTIMATE the willingness of developers to invest more in new landscape planting in return for relaxing non-viable retention of large trees. Too many trees forced to be retained don't make it to 10 years.

Space

I believe that we could improve our street trees by creating wider nature strips. There seems to be such a demand to "cram" trees, public utilities, footpaths into such a narrow strip of land? To the point that it's not sustainable? Correct species selection and planting location (i.e. Don't plant trees in front of lamp post or just next to or above domestic sewer junctions) at the development stage will also minimize long-term issues. To a large degree many of the issues relating to street trees could be minimized by correct planning process and

the understanding of how trees grow within the urban environment. Another key point is aftercare correct tree training / proactive pruning programs to correct tree growth at a young stage.
The most significant barrier to provision of successful street trees that I have experienced is space, both above and below ground, and the very substantial costs of creating this space if it does not already exist.

Soil
Soil condition is generally clay, avoid changed profiles and choose trees that will grow in existing conditions - more long term sustainable.

Services
We are currently developing an agreement in principle with the electricity supplier regarding tree planting under power lines and species selection.
Services are everywhere, cannot be governed by these.

Water
Water restrictions have the potential to have a huge affect on the urban forest. At Unley we have concerns with our street tree asset in particular from the lack of water. Furthermore, we have had to introduce strategies within our parks and reserves to save our trees of importance. This has occurred due to having to in many cases having to 'turn off' our park/reserve watering systems.
We live in a Wet Dry climate with no water restrictions. One of the biggest issues we face is old planting techniques which see large mature trees fall in cyclonic winds.

Species selection
The Council wishes to decrease the use of exotic species to retain/re-create the sense of local identity and reduce the nutrients load on the waterways causing nitrification of our lakes.
I have been researching an alternative to the box tree, which in Nedlands arouses strong opinions, mostly anti. Still no one tree species ticks all the boxes on suitability to climate, soil, leaf drop. There must be something better than London Plane trees which are going in now.
Trialing alternative/new species and planting techniques is often limited to successful negotiations with developers of new residential estates due to the limited resources of Council.
I am prepared to trial species unusual or not known to grow in our area. I have been doing trials on different trees for over 10 years with varied success. Trees that do well in local gardens do not necessarily do well in streetscapes. I am not a qualified arborist, I do have a good grasp and understanding of what species do well with frost, alkaline soils and a rainfall of less than 350mm.
Using drought proofing tree planting techniques (Soil Conditioners) and drought tolerant species
We try to stay with drought tolerant species that grow quick and can withstand a certain amount of abuse.

Other
Could this survey be conducted across related professions &; industries too e.g. development, natural resources, landscape architecture.

15.2 Appendix B

Appendix B comprises supporting information for the Metropolitan Adelaide Study presented in Chapter 11.

15.2.1 Appendix B1: Information sheet

THE UNIVERSITY OF ADELAIDE
AUSTRALIA

SCHOOL OF ARCHITECTURE,LANDSCAPE ARCHITECTURE AND URBAN DESIGN

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Tree Sensitive Urban Design Study: Information Sheet

Dear *****

I am currently undertaking research towards a PhD at the University of Adelaide, school of Architecture, Landscape Architecture and Urban Design. My research topic focuses on better ways of designing urban streets to accommodate natural processes in urban infrastructure. In particular, I am investigating the role of street trees, including the role of trees in urban streets, problems and issues associated with street trees, and improved practices to: provide more space for street trees, both above and below ground; provide the necessary resources for street tree growth, including water; and, reduce conflicts between street trees and urban infrastructure.

Possible benefits of my research will possibly include new guidelines for urban streetscape design and street tree planting, and improved processes for delivering multi-disciplinary projects.

As part of my research I wish to interview practitioners involved in the planning and design of streets and the planting and management of street trees. It would be appreciated if you could participate in an approximate one hour interview at your office to explore these issues. The interview will have an informal format structured around a series of questions including your perceptions of street tree issues and current and future "best practices". The interview will be recorded and a transcription sent to you for any corrections or additions you feel appropriate. Your identity, and that of your organisation, will remain confidential. You will also remain anonymous in my published research, with any comments you make attributed to, for example respondent A, rather than by your name.

Please be assured that you may withdraw from the study at any stage if desired.

The project is being supervised by Associate Professor, Dr David Jones who may be contacted at david.jones@adelaide.edu.au, if you require any further information. Please also refer to the attached independent complaints form.

Yours sincerely

MARTIN ELY
PhD Candidate

15.2.2 Appendix B2: Consent form

THE UNIVERSITY OF ADELAIDE HUMAN RESEARCH ETHICS COMMITTEE

STANDARD CONSENT FORM
FOR PEOPLE WHO ARE PARTICIPANTS IN A RESEARCH PROJECT

1. I, ... *(please print name)*

   consent to take part in the research project entitled:

   Tree Sensitive Urban Design Study

   ....

2. I acknowledge that I have read the attached Information Sheet entitled:

   Tree Sensitive Urban Design Study

....

3. I have had the project, so far as it affects me, fully explained to my satisfaction by the research worker. My consent is given freely..

4. I have been informed that, while information gained during the study may be published, I will not be identified and my personal results will not be divulged.

7. I understand that I am free to withdraw from the project at any time

8. I am aware that I should retain a copy of this Consent Form, when completed, and the attached Information Sheet.

9 I am aware that my interview will be recorded, and that I will receive a copy of the interview transcript summary for correction or addition of any further comments.

....
(signature) *(date)*

WITNESS

I have described to .... *(name of participant)*

the nature of the research to be carried out. In my opinion she/he understood the explanation.

Status in Project: ....

Name: ....

....
(signature) *(date)*

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15.2.3 Appendix B3: Interview schedule

Part A Council context

A1.What is your role in Council?

A2 What is the role of street tree planting in your Council area?

A3.What is the level of support for urban tree planting at the strategic level?

A4. Do you operate under a wider street tree planting strategy or master plan?

A5.What are the interactions between different disciplines within Council (arborists, engineers etc)?

Part B Issues

B1. What do you see as the main benefits of street trees?

B2. What do you see as the main issues or problems associated with street trees in your area?

B3.What do you see as the main constraints to successful tree planting and establishment?

B4.What do you see as the main threats to the future of street trees in urban areas?

Part C Practices

C1.What practices have you adopted, or intended to adopt, to grow healthier trees in urban streets, or to reduce tree/infrastructure conflicts? Including,

- Innovative streetscape design/ geometry
- Design of the below ground space
- Infrastructure planning and design
- Water management
- Tree species selection

C2. What practices do you consider to be the most viable to grow healthier trees in urban streets, or to reduce tree/infrastructure conflicts?

C3 What factors do you consider prevent or limit the adoption of these practices?

15.2.4 Appendix B4: Coded response data

The following section comprises 'chunks' of verbatim interview text, coded in accordance with the categories that emerged during the data analysis.

Street Tree Benefits

No	Category	Commentary text
1	Extent	*Their benefits are endless…*
2	Extent	'*There's a whole host of benefits.*' - E - 1
3	Extent	'*Do you want all the usual ones?*' - E - 2
4	Extent	'*Massive benefits.* *From financial to environmental to everything. The list is endless-all the things you get taught.*' - O - 1
5	Extent	'*For an urban landscape I think our urban forest is very important.*' - W - 2
6	Extent	' *Council sees street trees as very highly valuable, because the community does. The community here is pro-tree. A lot of that is due to amenity and property values, but not looking at the other values.*' - E - 4
7	Extent	'*Other officers in Council are starting to see things more from the horticultural perspective, starting to notice and value the other benefits-stormwater, shade, carbon-the environmental values in addition to amenity and aesthetics.*' - E - 4
8	Extent	'*Street trees, in general, play a huge part in the social/cultural/environment in NPSP.*' - E - 5
9	Extent	'*Huge benefits.*' - W - 6
10	Extent	'*Where to start?*' - O - 4
11	Extent	'*I suppose biodiversity and shade are the two really big points with our street tree plantings in the City.*' - O - 4
12	Extent	'*For me it's, shall I do them in order?*' - O - 5
13	Extent	'*Two fold.*' - E - 7
14	Extent	'*Their benefits are endless…*' - W - 5
15	Suburb character amenity\Amenity	'*I guess the main one would be the amenity value, shade.*' - E - 1
16	Suburb character amenity\Amenity	'*For this Council area-maintenance of the character and amenity of the area.*' - E - 2
17	Suburb character amenity\Amenity	'*Tree planting is a relatively cheap way of improving the amenity and character of an area. If you had to do it some other way, under the Development Plan say, with attractive housing form etc, it would cost a lot. Trees provide shade. They soften the line of the road and infrastructure, and create light and shade.*' - E - 2
18	Suburb character amenity\Amenity	'*The amenity value.*' - E - 3
19	Suburb character amenity\Amenity	'*Obvious psychological value-improving amenity, aesthetics.*' - W - 1
20	Suburb character amenity\Amenity	'*Amenity*' - W - 3
21	Suburb character amenity\Amenity	'*Form character and amenity.*' - O - 6
22	Suburb character amenity\Amenity	'*The character and amenity is the main thing.* ' - O - 6
23	Suburb character amenity\Amenity	'*Basically we are establishing new suburbs so the role is to provide amenity and character.*' - O - 6
24	Suburb character amenity\Amenity	'*The aesthetics. The amenity of the streetscape.* ' - W - 6
25	Suburb character amenity\Amenity	'*Again I think fundamentally it is that issue of amenity.*' - O - 3
26	Suburb character amenity\Amenity	'*The amenity value of trees within a streetscape*' - O - 4
27	Suburb character amenity\Amenity\Visual benefits	'*Trees provide shade. They soften the line of the road and infrastructure, and create light and shade.*' - E - 2
28	Suburb character amenity\Amenity\Visual benefits	'*They play a visual role.*' - E - 5
29	Suburb character amenity\Amenity\Visual benefits	'*The visual benefits are pretty high, that's the first one I think of,* ' - O - 2
30	Suburb character amenity\Amenity\Visual benefits	'*The aesthetics of it.*' - E - 7

31	Suburb character amenity\Amenity\Visual benefits	'*Within the urban environment trees play an important role in the establishment of visual amenity and visual quality?*' - W - 5
32	Suburb character amenity\Amenity\Visual benefits	'*Trees can be important in providing visual interest and the aesthetic benefits of their beauty in terms of form, colour, foliage, flowers, etc.*' - W - 5
33	Suburb character amenity\Amenity\Visual benefits	'*Trees can also provide privacy between pathways and houses. Trees can be used to screen undesirable views or activities, as well as providing a unifying element in parks, ovals and linear parks.* ' - W - 5
34	Suburb character amenity\Desirability	'*The amenity value. Your top suburbs are generally the eastern suburbs. Burnside is always known as the leafy suburb, it definitely gives you that appearance and appeal as you drive through there, nice big trees.*' - E - 3
35	Suburb character amenity\Desirability	'*I think it's important and it's so hard to get something established, let alone to get it to 100 plus years old is an incredible feat. You know how the landscape has changed and they've managed to survive all the digging and cutting and they deserve to live.*' - E - 3
36	Suburb character amenity\Desirability	'*When a person drives down the street, the biggest impact is the tree. And the leafiest suburbs, that's why the value of the houses are higher than elsewhere, because it's usually the leafy streets, or leafy suburbs.* ' - O - 1
37	Suburb character amenity\Desirability	'*I guess when people think of the eastern suburbs, they think of leafy green suburbs*' - E - 5
38	Suburb character amenity\Desirability	'*Other people? I went to this engineering conference last year, geotechnical, footing engineers, and they had their reasons why they have trees. I really don't think they knew why we have trees. They would prefer no trees at all. It makes their footing designs easier. But I think when they did sort of admit that trees were good it was to make suburbs not boring. I think they were clear that without trees suburbs would be dead boring.*' - O - 5
39	Suburb character amenity\Desirability	'*There's no doubt that a good tree lined street is desirable.*' - E - 7
40	Suburb character amenity\Desirability	'*Aesthetics-clearly the residents want to see green streets*' - E - 7
41	Suburb character amenity\Desirability\Streetscape appeal	'*Look at it a bit simply. Aesthetics-tree lined avenues bring a sense of calmness and pride if done well. They can change the whole aesthetics of a streetscape. The trees don't even have to be huge and imposing. A good contrast, buffer to the built form. Softens it.*' - E - 2
42	Suburb character amenity\Desirability\Streetscape appeal	'*The usual list of environmental benefits is ok-but more often than not you notice when you drive down a street that has been upgraded. If you get good street trees you get good aesthetic appeal.* ' - E - 2
43	Suburb character amenity\Desirability\Streetscape appeal	'*Calmness to people. Sense of pride-people will take pride in their properties in a good street. In this Council area people have always had good streetscapes, need to maintain it. Sense of ownership instills some passion to maintain the existing and then people also want more*' - E - 2
44	Suburb character amenity\Desirability\Streetscape appeal	'*The aesthetic value is huge-it puts on retail property values, as well as a healthy environment.* ' - O - 1
45	Suburb character amenity\Desirability\Streetscape appeal	'*Visually-aesthetic streetscape appeal.*' - E - 5
46	Suburb character amenity\Desirability\Streetscape appeal	'*Obviously the visual look of the street-it totally lifts the look of a street.*' - W - 4
47	Suburb character amenity\Identity, character	'*Place making.*' - W - 3
48	Suburb character amenity\Identity, character	'*Trying to establish character in some of the townships.*' - O - 6
49	Suburb character amenity\Identity, character	'However *street trees are vital because they provide physical and visual links along the streets throughout the suburbs.* ' - O - 2

50	Suburb character amenity\Identity, character	'*There's some iconic streets, if you are talking about Plane trees even on Frome Road where they are all higgledy piggldy, but the overall effect is quite phenomenal. There's Victoria Avenue, even Norwood Parade. You could argue that the selection of the sideroxylon is messing up their pavement, but they have an impact there. So it's defining that place.*' - O - 3
51	Suburb character amenity\Identity, character	'*We tend to try and limit the number of species mixed within a street so that we have a single character for a street, so there's that whole presentation of a street, continuity of the street environment. Aiding the reading of the street environment, but also trying to come up with character references for areas within the city, which are uniquely Salisbury.*' - O - 4
52	Suburb character amenity\Identity, character	'*Third I would say is to define the character of an area, so people with disabilities or sight impaired, hearing impaired, trees really help them to navigate. And are often forgotten about.*' - O - 5
53	Suburb character amenity\Resident support	'*Trees are one of the many issues that come up in the public realm, which can be very heated either way.*' - O - 4
54	Suburb character amenity\Resident support	'*We do public consultation, so we get out and actually talk to people in their street in relation to our renewal process. So we have streets where the people have very big dislike of trees, or those who have a dislike of one tree, but in the process of the conversation say they love trees. Or there are those who don't want you to touch a tree because it's been there for ages and it brings in the bird life and everything else. I suppose we are not uncommon to what other local governments would experience when dealing with trees. It can become a very interesting situation, especially when you see it being played out in a street meeting. The social politics of where people sit within a street environment. In all the information we send out to the public, we list all the benefits, the health benefits, the environmental benefits. But when it comes to the face to face consultation, sometimes those things don't get heard.*' - O - 4
55	Suburb character amenity\Resident support	'*Our residents see huge benefits. Very protective of the tree stock. There's very little we could get away with in relation to trees without it being picked up. We're very conscious of that, of how protective the residents are for the trees. You only need to remove a tree you haven't given notification to remove and you'll find out how unhappy they are.* ' - E - 6
56	Suburb character amenity\Resident support	'*Our policy talks about, we have to give 2 weeks' notice to residents for the removal of trees-and that's to I think 50m from the tree. So that's all locked up in our policy. So we certainly recognize the value of them.*' - E - 6
57	Suburb character amenity\Resident support	'*The residents want it.*' - E - 7
58	Economic\General	'*Financial benefits*' - E - 4
59	Economic\General	'*Plus a lot of financial benefits.*' - O - 6
60	Economic\General	'*But I think there is an economic value to the city as well-to maintain it.*' - E - 6
61	Economic\Property values	'*Will increase property values? People don't understand how it can happen, unless they go into an area with established tree cover and see the effect. I grew up in Marion, where they were loathe to put in street trees, and usually planted plums. Went back there a year ago-Council has done some street tree planting and used some decent tree species. It has changed the whole amenity of that street. Portrayed it as a higher class area,*' - E - 2
62	Economic\Property values	'*And property values as well, that factor come into it.*' - E - 3
63	Economic\Property values	'*The aesthetic value is huge-it puts on retail property values, as well as a healthy environment.* ' - O - 1
64	Economic\Property values	'*Land valuation.*' - W - 3
65	Economic\Property values	'*Burnside is a good example of that; they've recognized the benefits to property values. You try to explain it to people, so you say look at Payneham and Norwood. They are suburbs adjacent to each other, and property values in Norwood are a lot higher.*

		What is the character of Norwood determined by, as well as some nice buildings they have some really nice streetscapes. You've got Payneham and everything is butchered and dry.' - O - 6
66	Economic\Property values	'*The real estate agents want it because it makes it easier to sell the house.* ' - E - 7
67	Economic\Envtl services	'*Reduced particulate emissions reduce types of brain cancers. Economic benefits of that one small component would be in the millions in cities in health funding. Relating it directly to trees. Studies are starting to quantify it. Economists are doing it, not greenie tree huggers so becoming more reliable and compelling.*' - E - 4
68	Environmental\General	'*And then the environmental benefits-pollution, provision of oxygen, all that sort of stuff.*' - E - 1
69	Environmental\General	'*I see it as being the lungs and trying to keep the place cool*' - E - 3
70	Environmental\General	'*The aesthetic value is huge-it puts on retail property values, as well as a healthy environment.*' - O - 1
71	Environmental\General	'*I think obviously the environmental issues from my viewpoint stand out.*' - E - 5
72	Environmental\General	'*And now it's being acknowledged, that environmental role.*' - E - 5
73	Environmental\General	'*And obviously there are benefits for birdlife, oxygen, environmental issues.*' - W - 4
74	Environmental\General	'*There are a lot of environmental benefits that we are all aware of. I think the environmental factors are the critical ones.*' - E - 6
75	Environmental\General	'*And of course the environmental side too-there are huge benefits in having the right sort of tree.*' - E - 7
76	Environmental\General	'*And environmental-we are all becoming too aware of the importance street trees are now playing in our daily lives.*' - E - 7
77	Environmental\General	'*Apart from the environmental benefits there are also the social benefits as well.*' - W - 5
78	Environmental\Climatic\Shade\Amenity	'*I guess the main one would be the amenity value, shade.*' - E - 1
79	Environmental\Climatic\Shade\Amenity	'*Provision of shade and shelter belts.*' - E - 2
80	Environmental\Climatic\Shade\Amenity	'*Trees provide shade.* ' - E - 2
81	Environmental\Climatic\Shade\Amenity	'*Shade and shelter.*' - W - 1
82	Environmental\Climatic\Shade\Amenity	'*shade,*' - E - 4
83	Environmental\Climatic\Shade\Amenity	'Also *shade is very important.*' - O - 2
84	Environmental\Climatic\Shade\Amenity	'*Amenity, including the establishment of a microclimate is important in a concrete and bitumen dominated suburb in particular. It is generally cooler under a tree with a bit of shade. Much more pleasant.*' - O - 2
85	Environmental\Climatic\Shade\Amenity	'The *availability of trees so cars can park under them, so people can sit under them. That is all so important.* ' - W - 6
86	Environmental\Climatic\Shade\Amenity	'*I guess all we (the landscape design team) tend to inform residents of the benefits of shade and the biodiversity.*' - O - 4
87	Environmental\Climatic\Shade\Amenity	'*Number one is shade, and obviously you can go on about that forever.*' - O - 5
88	Environmental\Climatic\Shade\Amenity	'*So people can walk to the shop and shelter from the rain. And it can't be provided any other way economically.*' - O - 5
89	Environmental\Climatic\Shade\Amenity	'*We don't get torrential tropical downpours, we get showers, so even in winter a trees fine 90% of the time.*' - O - 5
90	Environmental\Climatic\Shade\UHI	'*Cooling, the environmental cooling.*' - E - 3
91	Environmental\Climatic\Shade\UHI	'*Lowering air temperature.*' - W - 1
92	Environmental\Climatic\Shade\UHI	'*It's an important aspect of cities climate control tool. To assist us in cooling. So I think they have a large benefit.*' - W - 2
93	Environmental\Climatic\Shade\UHI	'*Reducing urban heat island effects.*' - W - 3
94	Environmental\Climatic\Shade\UHI	'*Cooling.*' - W - 3
95	Environmental\Climatic\Shade\UHI	'*The cooling to houses.*' - W - 6
96	Environmental\Climatic\Shade\UHI	'*And there are certainly some tremendous benefits of solar access or shading (depending on the orientation of the houses in each street.)* ' - O - 3
97	Environmental\Climatic\Shade\UHI	'*As well as environmental considerations in relation to builtform-with shading particularly.*' - O - 3

98	Environmental\Climatic\Shade\UHI\Climate change	'*Climate change.*' - W - 2
99	Environmental\Climatic\Shade\UHI\Climate change	'*I guess the other view point we have been trying to portrait is with climate change being such a political issue at the moment, trying to change people's focus in relation to the benefits trees have in relation to the climate change information, and the increase in change in weather and climatic conditions, that will not be favorable to the plains area without trees.*' - O - 4
100	Environmental\Climatic\Shade\UHI\Road pavement	'*To some extent, I'm not sure about the full benefits, but increasing the lifespan of road pavements-has been researched and has its benefits.*' - W - 1
101	Environmental\Climatic\Shade\UHI\Road pavement	'*Tim Johnson, has a belief that a street tree shading of bitumen will extend the life of bitumen, and things like that. But for me, I kind of believe that, but I still don't know why we build roads in bitumen. We could use concrete segmented pavers. So by saying they extend the life of bitumen just perpetuates the myth that our streets need to be 5 m wide bitumen strips. I would like to see the evidence. But I would more say, why can't the road be just dirt?*' - O - 5
102	Environmental\Climatic\Shade\UHI\Glare	'*Potential to reduce glare and reflection*' - W - 1
103	Environmental\Atmospheric\Air quality	'*pollution, provision of oxygen*' - E - 1
104	Environmental\Atmospheric\Air quality	'*Absorbing CO2, and producing O2.*' - W - 1
105	Environmental\Atmospheric\Air quality	'*Carbon emissions.*' - W - 3
106	Environmental\Atmospheric\Air quality	'*Carbon sinks*' - W - 3
107	Environmental\Atmospheric\Air quality	'*carbon*' - E - 4
108	Environmental\Atmospheric\Air quality	'*The role that trees play in photosynthesis process.* ' - W - 6
109	Environmental\Atmospheric\Air quality	'*oxygen,*' - W - 4
110	Environmental\Water\Runoff	'*Modifying water runoff and stormwater.*' - W - 1
111	Environmental\Water\Runoff	'*Stormwater management*' - W - 3
112	Environmental\Water\Runoff	'*stormwater*' - E - 4
113	Environmental\Water\Runoff	'*Initial water-holding capacity within the foliage, holding up that runoff and water running directly into the kerb and water table.*' - W - 5
114	Environmental\Water\Quality	'*Improving water quality.*' - W - 1
115	Environmental\Soils	'*Stabilizing soils in some situations.*' - W - 1
116	Ecological	'*Food and shelter for wildlife.*' - W - 1
117	Ecological	'*A lot of the community, not all, has long valued biodiversity because of the remnant vegetation in the hills. A major focus of Council has been their conservation. But a lot of the woodland trees are not protected on residential property; they are below the 2m size.*' - E - 4
118	Ecological	'*Increase in biodiversity is a big benefit with the fauna and birdlife it attracts.*' - O - 2
119	Ecological	'*The connection that trees have to bird corridors-and I generally refer to them as bird corridors and not biodiversity corridors. I think if you want a biodiversity corridors its more than just a line of trees, I think you need to have an understorey. A well structured understorey. I get people asking me; get more into urban forestry and biodiversity and plant up roundabouts. Well planting a roundabout is not biodiversity.*' - W - 6
120	Ecological	'*At a strategic level we are doing a biodiversity plan for the City, and one outcome may be we investigate doing an overarching street tree strategy-as some of the biodiversity recommendations in the biodiversity plan may interlink with that. We are half way through that at the moment; we've had meetings with community and State stakeholders. And one of the things that's often mentioned is what's the role of street trees in the biodiversity plan.* ' - W - 6
121	Ecological	'*Personally I'm not a real strong advocate in terms of biodiversity value-there's a couple of issues around that-we quite often have strident opposition to native species, from residents-it's quite a vexed issue native plantings.*' - O - 3
122	Ecological	'*benefits for birdlife*' - W - 4

123	Ecological	'*I guess all we (the landscape design team) tend to inform residents of the benefits of shade and the biodiversity.*' - O - 4
124	Ecological	'*I suppose biodiversity and shade are the two really big points with our street tree plantings in the City.*' - O - 4
125	Ecological	'*Then probably two is the biodiversity type things, like attracting birds, which then fertilize people's backyard fruit trees, or attract ants. That biodiversity is an important role, especially being in the outer suburbs near the hills.*' - O - 5
126	Social\Well being	'There's *also psychological benefits of trees-imagine trying to work or live in a place without any trees.*' - E - 1
127	Social\Well being	'*Can put a dollar value on some of it, measurables. But often not measurable, for example the psychological benefits.*' - E - 2
128	Social\Well being	'*Obvious psychological value-improving amenity, aesthetics.*' - W - 1
129	Social\Well being	'*The aesthetic value is huge-it puts on retail property values, as well as a healthy environment.* ' - O - 1
130	Social\Well being	'*We had issues last week where a bloke thought the tree out in front of his house belonged to him, so I've had to write reports explaining to him, and the Council, that its actually of benefit to the whole community and not just him. For some unknown reason they think their boundary is the kerb line, so therefore they own the tree and if they want it removed, they have the right to have it removed.*' - O - 1
131	Social\Well being	'*Mental health benefits-stress reduction, crime reduction, reduced road rage, reduced fatigue, reduced accidents.*' - E - 4
132	Social\Well being	'*Physical and mental health and lifestyle-making cities livable.*' - E - 4
133	Social\Well being	'*Health benefits.*' - E - 4
134	Social\Well being	'*Physical and mental health and lifestyle-making cities livable.*' - E - 4
135	Social\Well being	'*The most important benefit, they maintain quality of life and community. A lot of people don't see that.*' - E - 4
136	Social\Well being	'Physical *benefits and immense psychological benefits.*' - O - 6
137	Social\Well being	'*People's well-being.*' - E - 5
138	Social\Well being	'*I think it increases the value of the area-not just from a monetary perspective, but from that well-being side.*' - E - 5
139	Social\Well being	'*Statistics have shown that vandalism and crime is less in areas where the streets are filed/lined with trees.*' - W - 5
140	Social\Well being	'*As our surroundings become harsher, people become grumpier, things become hotter and they become even unhappier and it just snowballs. Trees have a lot to do with the environmental well being of our residents and ratepayers.*' - W - 5
141	Social\Well being	'Apart *from the environmental benefits there are also the social benefits as well.*' - W - 5
142	Social\Well being	'*I am concerned that due to the increase of urban consolidation we are creating small ghettos-where we are losing that softness and that connection with our environment.*' - W - 5
143	Social\Well being\Quantified	'*The spin offs are difficult to quantify. A lot of studies have done small components of that.* ' - E - 4
144	Social\Cultural	'*They can also form an iconic feature-or they might represent something like a memorial.*' - E - 1
145	Social\Cultural	'*A very large part in our history.*' - E - 5
146	Social\Cultural	'*Realistically-tree lined avenues are synonymous with Burnside's history*' - E - 5
147	Big tree argument	'*Golden Grove is simply poor tree selection. I think trees were selected on a theme, rather than longevity. So its fine, the trees have got 20 years. They look good. But 20 years is not enough for a tree. I reckon you need a kind of design criteria for a street tree. And 20 years is still a good wicket, given all your car impacts and oil and all those sorts of things. But I think if you looked at their design lifespan, I think you'd go their design life was 10 years. And we should be aiming for like 40 years. You're going to*

build this subdivision, here are the top 10 things you have to do, and one is to get 40 years out of your street trees. Because when you add up all the cost of them. The bigger they are the more benefits they provide.
' - O - 5

Street Tree Issues

No	Category	Commentary text
1	Comment	'*I personally I don't see any problems but the main issue we have is leaf litter.*' - E - 3
2	Comment	'*Perception-because they do have a cost.*' - E - 4
3	Comment	'*Actually getting them into the ground.*' - O - 6
4	Comment	'*The problems that get relayed back to us.*' - W - 4
5	Physical\Urban devpt\Urban infill	'*The other thing is development. We've got areas such as Magill and Tranmere, where it's been large blocks, the true quarter acre blocks, and the developers have been coming through for a number of years now, buying them up and obviously trying to maximize their returns. And the street tree always seems to conflict with the driveway.*' - E - 3
6	Physical\Urban devpt\Urban infill	'*Development impacts on space. And that's including crossovers, sealed surfaces. I find the amount of development is increasing, and so we are dealing with street trees being lost, and also limiting the number of trees in front of properties as they are being subdivided. And peoples preference for double driveways or crossovers, 6m crossovers.* ' - W - 1
7	Physical\Urban devpt\Urban infill	'*My main problem associated with street trees is the infill of new houses. Obviously when they put a new house in. They put in a new driveway and it always results in some sort of tree to be removed. And we get into a few arguments about that. We are slowly educating the planning to be mindful of these sorts of things. Because once you take them out you obviously can't put them back anywhere else.*' - O - 1
8	Physical\Urban devpt\Urban infill	'*Gawler has run out of land so what they are doing now is infilling and subdividing blocks.*' - O - 1
9	Physical\Urban devpt\Urban infill	'*Conflict with development.*' - E - 5
10	Physical\Urban devpt\Urban infill	'*Planning approve new developments. As Prospect has got a lot of large blocks and there's been a lot of subdivision over the years. In some cases you will find tree have to be removed, but not always. If it's a significant it has to go through that process, the government legislation. However I'm reluctant to remove younger, healthier trees, for the obvious reason they've got many years in them.*' - W - 4
11	Physical\Urban devpt\Urban infill	'*I have a lot of interaction with planners. As you can imagine a lot of development has occurred within West Torrens in the last 2-3 years. It's increased tenfold. Developments, subdivisions, housing, all of which effect both street trees and significant trees due to the fact that everyone wants to divide up their properties and place 2 or 3 houses on it. All of a sudden you have an existing cross-over that needs to be widened, and/or they want another cross-over on the other side. Where once we had verges that could accommodate 2 or 3 trees, now we find that we are losing one and we can only accommodate one. So that is a big issue, not only are we are losing a lot of trees but locations where we can put them.*' - W - 5
12	Physical\Urban devpt\Urban infill\Compensation	'So *we now do charge a fee for the removal of a street tree and also a charge on a replacement. So that's how we are sort of getting around it. Sometimes it can be a favour where it's a bit of a dog of a tree. We get a cheap return on our investment, but other times it can be quite a good tree and we have to argue the point. Sometimes you can get quite stroppy developers as we are not playing ball with them. If it is a really good tree we try to use the Burnley tree method to put a dollar value on the tree. Luckily we don't get too many of those where it's a nice100 year old plus*

		red gum or something like that. I'm happy we don't really have to test that avenue.' - E - 3
13	Physical\Urban devpt\Urban infill\Compensation	'*If we can't get a compromise where the cross-overs going to go, we will remove the tree. But there is a cost to be borne by the developer or whatever and generally replacement with either1 to 2 trees, whatever's appropriate. A case by case basis. Most times you prefer they go back and-try to relocate. If it's a case where a tree is in obviously in decline, or its not growing particularly well it's better to have it removed and get a new tree in there* ' - W - 4
14	Physical\Urban devpt\Urban infill\Implications	'*So in the future the urban landscape will not be created in streetscapes but in parks and reserves. We will still do traditional street tree planting, but not at the same level. More resources will go to parks and reserves. There are more open space opportunities for tree planting. Will not necessarily look at traditional avenues-but at cluster planting or island planting.*' - E - 2
15	Physical\Urban devpt\Urban infill\Implications	'*That's going to be more and more important as development narrows down with smaller blocks, and people not being able to get trees of any size onto their parcels of land. I think street trees will be the way we can get trees in.* ' - E - 3
16	Physical\Urban devpt\Urban infill\Implications	'*I think they play a vital role because of the smaller lot sizes and the larger houses in the newer areas in particular as there's no room for trees on people's blocks anymore. In the new suburbs, often the only places where you can put trees are the reserves.*' - O - 2
17	Physical\Urban devpt\New development	'*Not just in Council, within the development industry too, trees are seen as a necessary evil in some instances. A cost for developers. You need to watch out you don't get them trying to cut costs at that end. Trees are still the afterthought; they're not front of mind. People have got an idea they kind of like trees, but they're not really as important as the door knobs, the bin, the street lights. The developers want them to look good for that year they are selling the blocks. They're not too fussed if it's not really going to be too flash after that. They're gone and you are left with responsibility, that's why it's so important to make sure it's planted properly, that there's good stock. And make sure they know there's a fair chance of being checked up on. That accountability thing. Overall its consciousness thing the climate of consciousness needs to change for street trees.*' - O - 6
18	Physical\Urban devpt\New development\Establishment	'*Developers do their own tree planting.* *I'm trying to change things-and get all infrastructure put in before the blocks get sold. It's a hard battle but that's what we are trying to do. Because what happens down the track, someone comes in and buys a house, and they buy them in dribbles, so they landscape their front gardens, and the last thing they want is for us to come along and put a tree in it. So it gets missed out. Others people do want trees. So we want to get the developer to do it all at the beginning.* ' - O - 1
19	Physical\Urban devpt\New development\Establishment	'*As I said before they've got this mindset, if the developer puts them in that's the end of the story.*' - O - 6
20	Physical\Urban devpt\New development\Establishment	'*They haven't recognized the other requirements-to manage them and nurture them*' - O - 6
21	Physical\Urban devpt\New development\Establishment	'*Establishment. There's no understanding of the need for an establishment regime. Just stuck in the ground and left to a certain extent.*' - O - 6
22	Physical\Urban devpt\New development\Establishment	'*Not just in Council, within the development industry too, trees are seen as a necessary evil in some instances. A cost for developers. You need to watch out you don't get them trying to cut costs at that end. Trees are still the afterthought; they're not front of mind. People have got an idea they kind of like trees, but they're not really as important as the door knobs, the bin, the street lights. The developers want them to look good for that year they are selling the blocks. They're not too fussed if it's not really going to be too flash after that. They're gone and you are left with responsibility, that's why it's so important to make sure it's planted properly, that there's good stock. And make sure they know there's a fair chance of being*

		checked up on. That accountability thing. Overall it's a consciousness thing; the climate of consciousness needs to change for street trees.' - O - 6
23	Physical\Urban devpt\New development\Establishment	'*Residential developments are an interesting case in point. There are usually a number of conditions attached to a Development Application and amongst the conditions there can be a requirement to provide a landscape plan with the planting of street trees to be part of those conditions. This provides the opportunity to establish a hierarchy and street tree master plan. When the landscape plans are lodged I have the role in approving them and as part of that process I circulate them to a number of other people in Council that have an interest in open space, including the maintenance team and we make a determination on whether we think the landscaping appropriate or even if there is enough detail to assess it. It's encouraging that most of the developers engage a Landscape Architect to prepare the landscape plans for them, some don't and then you get sketchy plans with very little detail on planting methods. As a result and due to poor contract supervision a lot of those trees don't do particularly well. The unfortunate issue with badly planted trees or poor stock is that the problems don't show up for many years to come, after the developers have moved on and it is left to Council to shoulder the burden for any replacements.*' - O - 2
24	Physical\Urban devpt\New development\Establishment	'*Of course in a construction setting, when those trees are put in, is another vexed issue. We encourage developers to put trees in up-front, and have adequate protection measures. But given land values and lot sizes, and that sort of density, that's quite an issue. Generally there's a position that developers will look for certain high level of occupancy, into 70-80% even before they will consider rolling out street trees.*' - O - 3
25	Physical\Urban devpt\New development\Establishment	'*Which brings in another dilemma which is the consultation around that-people that purchase lots often are dealing with agents, who will tell them whatever they think that person wants to hear to sell the lot or a house and land package. So people have all sorts of expectations of what they are going to get, or they don't want anything at all. So by delaying it then there's a communication about getting the trees in.* *Council's position fundamentally though is that this is a developer responsibility.* ' - O - 3
26	Physical\Urban devpt\New development\Footpath	' *Specific to the street trees, probably the largest issue we have is footpaths-and traditionally (say for the last 30 years) footpaths would be placed by the property boundary, and in effect you're defining the verge. In more recent times there's been a move to place footpaths to back of kerb. And there are a couple of ideas around why we do that. Fundamentally it comes down to an issue of maintenance. Council is in the traditional business of mowing or maintaining verges. By putting the footpath to the back of the kerb, then definition of boundary less defined. And the intent is that the actual occupant then takes it over, the maintenance of the verge. What you lose though is control of what happens in that verge. Particularly an issue for street trees. So we are reviewing that. And in fact the latest Greenfields development-the Playford North project in particular-footpaths will be to property boundaries so that we can have better control over that public realm in the streetscape.*' - O - 3
27	Physical\Urban devpt\New development\Footpath	'*But I think that at a strategic level, the biggest shift that I alluded to earlier is this change in the physical makeup of that verge, and clearly defining what is the verge and being responsible for it. I think there's tremendous benefit and we need to take that up. And no longer just by default pretend that it's not there and hope that someone else is going to look after it, and they'll plant their palm trees or heaven knows what else, on our verge.*' - O - 3
28	Physical\Urban devpt\New development\None	'*It's a very different character you get here to down on the plains.* *And we don't have a lot of subdivisions or housing developments where you tend to get that street tree planting happening.* ' - E - 1
29	Physical\Space\Verge	'*One of the biggest impacts in the street is the street trees. But it's the last thing they try and make a space for. TREENET have talked about the*

		space for a tree, but it just doesn't seem to happen.' - O - 1
30	Physical\Space\Verge	'*The lack of physical space to plant trees, particularly in the verges is probably the biggest issue.*' - O - 2
31	Physical\Space\Verge	'*And defining that verge.*' - O - 3
32	Physical\Space\Constraints	'*We are starting to look at whether we can use that borrowed landscape idea, so planting in private property rather than on the footpath.* ' - E - 1
33	Physical\Space\Constraints	'*Footpath requirements getting wider, so the location of services are getting more problematic-seem to be more and more underground services which conflicts for space for root development.* ' - W - 3
34	Physical\Space\Constraints	'*A lot of conflicts for space.*' - W - 3
35	Physical\Space\Constraints	'*It's making sure you allow sufficient room for the tree to grow unimpeded and doesn't have that interaction with the adjacent infrastructure. This also takes into consideration the canopy development of the tree. Because in the new areas they're building smaller roads, they're having shorter frontages on properties. So you can't plant a tree that's got a big strong canopy, because you are going to have it sitting on people's verandahs, and they want us there every five minutes to cut them back. So we have to be mindful that where we have these changes in urban design and construction, that we cater for the respective setbacks and so on.* ' - W - 6
36	Physical\Space\Constraints	'*Other problems? The thing that I've found, this is an old suburbs, and a lot of these trees were planted before Telstra and fibre optics cables-so it's sometimes quite difficult to now to relocate or replace tree in its existing spot. Because the cabling went in after. Not so much the water, and gas, that's generally been around a long time. But there have been a lot put under ground. So you may remove a tree there, it could be in the best position as far as balance goes, but you can't put it back there for these reasons. So there are issues there talking to residents about where it's going to go.*' - W - 4
37	Physical\Space\Constraints	'*Probably the main area is the conflicts with infrastructure. We're very tight, we're inner suburban, and we're dealing with narrow footpaths in the context of people who want a canopy tree. And it's not always possible. Where we may want to plant trees that are 10m high in Parkside, we're quite often unable to do that. It's restrictive. The issue of planting in narrow places with little room for trees to expand into. Quite often we're planting in footpath widths that are 2m wide, and you plant in a 300mm nature strip area, knowing full well that in years to come the trees going to do damage to the kerb and water table. Those sorts of issues.*' - E - 6
38	Physical\Space\Constraints	'*Then you get onto infrastructure that's there. And I'm not really talking about our roads, footpaths and kerbing. It's the power lines, sewer, all those constraints they throw at us that restrict us actually having successful trees. When you work out all the constraints you have to deal with, it's a wonder we've got any trees at all. With ETSA you can't plant under a pole, you have to be so many metres back from a crossover, and the planners that approve double crossovers when there's no room for a double crossover and there's trees in the way If you've got a magnificent street tree, and the planners approve a masonry wall on the boundary, you have to be so many metres away from it.*' - E - 7
39	Physical\Infrastructure\Conflicts\Infr damage	'*As I said before, the introduction of a living element in a non-living structure- power lines, the utilities, services.*' - W - 2
40	Physical\Infrastructure\Conflicts\Infr damage	'*When Robert goes in to build a new road, they will look at what caused the failure of the road, and assess the factors such as it may have been the poor subgrade or the street trees have contributed to the failure of the road pavement. It may have been that it's a pocket of say Gilles Plains where the soil is extremely reactive, and what's contributed to the buckle and heave in the road is that. In some instances we've got some Eucalypts that are drawing extensive amounts of moisture from the road surface.*' - W - 6
41	Physical\Infrastructure\Conflicts\Infr damage	'*Our engineer's assessment is based around providing a safe road network. It might be that the roads got only minimum buckle and heave*

		but it may be in spots that you can cause water ponding. And the way the soil moves up there. Season to season you can get a variance of 100-150mm in the swelling of the clays. Then we've got water lying in streets which is a huge safety issue, and it's also putting us at risk of localized flooding. ' - W - 6
42	Physical\Infrastructure\Conflicts\Infr damage	'*Infrastructure damage is probably the biggest concern I have.*' - E - 7
43	Physical\Infrastructure\Conflicts\Tree impacts	'*Other problems? The thing that I've found, this is an old suburbs, and a lot of these trees were planted before Telstra and fibre optics cables-so it's sometimes quite difficult to now to relocate or replace tree in its existing spot. Because the cabling went in after. Not so much the water, and gas, that's generally been around a long time. But there have been a lot put under ground. So you may remove a tree there, it could be in the best position as far as balance goes, but you can't put it back there for these reasons. So there are issues there talking to residents about where it's going to go.*' - W - 4
44	Physical\Infrastructure\Conflicts\Tree impacts	'*Infrastructure damage is probably the biggest concern I have.* *Some of those issues go back a long time, because we are talking about some of our older trees, 60-70 years now. It's become very hard to rebuild that infrastructure around those trees.*' - E - 7
45	Physical\Infrastructure\Conflicts\Tree impacts	'*There is a tendency to actually remove the tree or part thereof to rebuild the infrastructure.*' - E - 7
46	Physical\Infrastructure\Hardscape\Damage	'*And also I have to acknowledge that a main issue with street trees is infrastructure damage-footpaths, kerb, water table. Charles Sturt is pretty flat, and there is fine line to keeping that water moving. With time some of that resolution may come into different designs-why do we need straight concrete lines and water fall down to the end of the street to a SEP. So that's where the interaction between designers, landscape designers, also architects having an input into modifying stormwater runoff.* ' - W - 1
47	Physical\Infrastructure\Hardscape\Damage	'*Port Adelaide has similar issues, similar climatic conditions, similar soils, with some variation. West Torrens is similar.*' - W - 1
48	Physical\Infrastructure\Hardscape\Damage	'*Fear of damage to infrastructure from roots including footpaths, road pavements and buildings. I believe this fear is often unfounded and unfortunately spreads to the general population.*' - O - 2
49	Physical\Infrastructure\Hardscape\Liability	'*The biggest risk for us as a Council is the public liability risk-because we are required to provide a clear pedestrian footpath-and we put a living element next to it which intrudes into the footpath causing trip hazards. A major headache and not an easy one to resolve. So its damage to infrastructure I suppose, damage which is caused by a living tree-root invasion, which ends up causing public liability issues.*' - W - 2
50	Physical\Infrastructure\Services	'*Compromising services; water, sewer, telecommunications, ETSA.*' - O - 2
51	Physical\Infrastructure\Services	'*The other thing that's a huge impact on the street tree planting too, is the extensive resources required with preparing a street for planting. We go out and do full service locations-we have to take into account the usual-gas, electricity, water, sewer, and the telecommunications infrastructure. And it's such an exhaustive process just getting the contractor to do that for you.*' - W - 6
52	Physical\Infrastructure\Services	'*Services are a universal issue. In new areas common services trenching is certainly better than having things up in the air and all over the place.*' - O - 3
53	Physical\Infrastructure\Services\ETSA pruning	'*Planting underneath powerlines is one of the other main issues, because we are in a high bushfire prone area. ETSA come along and just butcher the trees under power lines, because that's the legislation. So we're working with ETSA to try and come up with different solutions to planting near powerlines. So that we can preserve the character of the Hills, because otherwise it gets destroyed.*' - E - 1
54	Physical\Infrastructure\Services\ETSA pruning	'*And also identifying those iconic trees-we've got an Oak tree in main street of Oakbank that in the past had a square cut out by ETSA around the power lines. So we're getting ETSA to be more sensitive pruning that particular tree.*' - E - 1
55	Physical\Infrastructure\Service	'*One problem I have is the ETSA pruning. As much as you hound them,*

	s\ETSA pruning	*the contractors, they say they are going to do this and do that, but generally the job doesn't quite get done as well as you would like.*' - O - 1
56	Physical\Infrastructure\Services\ETSA pruning	'*Conflicts with power lines is no doubt a major issue for the Council-particularly mature street trees-having had very little vegetation clearance in the past has now seen major issues at the moment with the clearance of huge amounts of canopy around power lines-which ultimately will have severe health impacts. Council has always fought very strongly to protect its trees. I think because the job hasn't been done in the past, the impact now when they are actually doing it is quite severe.*' - E - 5
57	Physical\Infrastructure\Services\ETSA pruning	'*You talk to neighbouring Council's where the clearance work has been undertaken, even though it's probably not to the satisfaction of Council, but because it hasn't been done for years and years in this Council area, with the regime of people in at ETSA at the moment wanting to undertake the works it in accordance with regulations, the impact on the trees is quite significant.* ' - E - 5
58	Physical\Infrastructure\Services\ETSA pruning	'*I think in the past the Council and the staff involved insisted on clearance being undertaken in the right way, to arboricultural standards. It might have been all a little too hard previously. And perhaps it was viewed the Council was too hard to deal with, and to go on and do another Council area. But the current ETSA staff are very insistent on undertaking the works, as its in the regulations, but not doing it in the past has probably caused more of an impact on trees at the moment.*' - E - 5
59	Physical\Infrastructure\Services\ETSA pruning	'*The other issue is ETSA pruning. Which to me essentially boils down to, ETSA aren't here enough. Once per year, in a day they want to finish a road, or every 2 years, and you can't manage a tree by doing that. It's a very difficult issue, but I think that's what it boils down to. And also you think, why does it need it?* ' - O - 5
60	Physical\Infrastructure\Services\ETSA pruning	'*Here we've got fire risk categories, and they need something like 2m clearance or more. So it's like, you're pruning for 2 m clearance every year, some trees are never going to re-grow again and others will be back to the wire in 2 weeks. Some will never recover. You need to have tree types A, and tree types B and have a different clearances. That would be your starting point, whereas their contractors and their specifications are pretty much it's that. And otherwise you're going to get a bushfire. And that's wrong. Scientifically it's wrong.*' - O - 5
61	Physical\Infrastructure\Services\ETSA pruning	'*ETSA are a problem and they have always been a problem. Their disregard of correct pruning techniques, hiding behind the claim they must provide power to customers, at the expense of Street trees, is false and irresponsible.*' - W - 5
62	Physical\Infrastructure\Services\ETSA pruning	'*There are better ways of pruning. In this day and age with documented and proven results (from Arborists and Academic's in the field), with growth rates on trees less than 100mm per year, why are they clearing 1.0 to 1.5 metres as an 18 month to 3 year* ' - W - 5
63	Physical\Infrastructure\Services\ETSA pruning	'*I was a contractor to ETSA at one stage of my working life, for a short period, supervising pruning trees from power lines. If ETSA took the appropriate care of their infrastructure as they should, half of the problems that they blame on trees would not occur. It is a very sore spot with me. When you have wooden cross arms that have been there for the last 20 years or more, if a bird landed on them they'd fall apart. But because a limb brushes up against a line and causes movement due to wind and it causes a short or a fuse to shut down, ETSA will always blame the tree. It's not the trees. It is poor infrastructure management, at the expense of trees. I would like to bet that if the money spent on removing limbs from trees was spent on infrastructure maintenance, outages would drop significantly and only the occasional tree may, only may, have a need to be trimmed.*' - W - 5
64	Physical\Infrastructure\Services\Private	'*The other concerns raised are to do with private infrastructure- sewer and stormwater networks, as well as structurally house elements. The contractor gets called to the private residence fixes a stormwater pipe that's broken, or a sewer pipe that's blocked, or discovers termites, with the offender being the tree in front of the property, or next door or where ever else within the street. We've come across a large number of stories like that.*' - O - 4

65	Physical\Water\Impacts	'*I've found the biggest strain with the tree network, over the last 8 years, has been the climatic conditions. It's had a hell of an impact on streetscapes. It's caused a lot of failure of branches. A lot of trees have died, so that shows those species were probably not the best choice. But we weren't to know.*' - W - 6
66	Physical\Water\Impacts	'*And water restrictions, there's also options, not so much for the street trees, but in land divisions where there's requirements for buffers*' - O - 3
67	Physical\Water\Impacts	'*I guess watering-this is a problem now when you put new trees in. I personally like putting new trees in-but there's a high water cost now. I guess that's ok if we can maintain our level 3. But we will have big problems if it goes to level 4, because we don't have access to any other, I was going to say bores but I don't think that's a long term solution anyway. As I understand, some Council's that are now on bore water, it's too saline so they can't use it anyway. So I feel that water is potentially a big problem, but I wouldn't say it's a huge problem at the moment.*' - W - 4
68	Physical\Water\Impacts	'*A bit of a personal view of mine. I see water restrictions having a significant impact on our tree stock.*' - E - 6
69	Physical\Water\Impacts	'*A bit of a personal view of mine. I see water restrictions having a significant impact on our tree stock.* ' - E - 6
70	Physical\Water\Impacts\Sources	'*From a trees point of view getting water to the root zone in a paved environment is a major issue.*' - O - 2
71	Physical\Water\Impacts\Sources	'*People used to water nature strips, and the grass areas their side of the fence. I think that moisture in a lot of instances got to the trees. Well that's been excluded from the equation and the trees are suffering.* ' - W - 6
72	Physical\Water\Impacts\Sources	'*Problems are really with climate change and/or the drought we've had over the last few years. These trees are now seeking moisture elsewhere. To plant a tree and have a mature tree covered by bitumen and paving, small nature strips, they've only got a small area to source water and/or nutrients in the soil. This can create a problem as they will definitely go for the front gardens-because there's generally moisture there. So it can create a problem between residents and Council, even though they say they love trees having the tee there, that tree is attacking their foundations and causing cracking. But I believe it's not just the problem of the tree-it's just the general drying out of. Soils. And you have to put that across to people, don't blame the tree. That's what I've found in the last few years.*' - W - 4
73	Physical\Water\Impacts\Sources	'Fundamentally *in Unley, because of all those issues of the tightness. Trees have got 3 places they can get their water from.* *They can get it from under the road* *They can get it in the nature strip area, or the kerb to boundary* *Or they can get it from the front yards of people's properties.* *What we've found with water restrictions is people have stopped watering their front yards like they used to.* *And they're not allowed to water their nature strip.* *And trees don't get much water from under the road.* *So I have huge concerns for the urban forest of the future.*' - E - 6
74	Physical\Water\Impacts\Sources	'*The problem is not during winter that the trees need the water, but in summer, and that's when it's not raining, usually, and we're getting long dry spells. And that's when people are potentially not watering much. So the question is where does a tree that transpires 100 litres a day get its water from during that period? That's going to be our challenge in the future. If it doesn't rain during summer then how do you get your water to your mature trees? You have got to hope they have got a reserve that keeps them going.*' - E - 6
75	Physical\Water\Impacts\Mature trees	'*I've found the biggest strain with the tree network, over the last 8 years, has been the climatic conditions. It's had a hell of an impact on streetscapes. It's caused a lot of failure of branches. A lot of trees have died, so that shows those species were probably not the best choice. But we weren't to know.*' - W - 6
76	Physical\Water\Impacts\Mature trees	'*Because of the climate we have had quite an issue with established trees-its undeniable that there is an impact with what we consider to be well established trees, have certainly shown signs of stress. We've had to*

		do some remedial work, applying Seasol or trying some other feeds on trees, or even putting in sub-surface irrigation.' - O - 3
77	Physical\Water\Impacts\Mature trees	'*Around the old established areas, say the boulevards around the Civic precinct, there were overhead sprays, pop ups in the verge areas with turf, and then you have trees that have been established for 10-20 years , so quite major trees. Now we are unable to water, so that irrigation has been off for 2-3 years, we no longer have the turf. We are retrofitting sub-surface systems in those locations. And that's been quite a process, and also liaising with SA Water to get water meters etc. The logistics of that has been an on-going issue.*' - O - 3
78	Physical\Water\Impacts\Mature trees	'*We have noticed over the last 12 months or so, whether one would blame climate change or not, a lot of older street trees, species like Queensland Box, are struggling with the dry conditions. In areas where irrigation has abutted a street tree, we have had street trees really suffering .They have been relying on this supplementary watering for many years and now the supplement watering of the park has been terminated, they can't cope.*' - W - 5
79	Physical\Water\Practices	'*They have done some trials putting in those water rings. Looking at different soil additives.*' - O - 3
80	Physical\Water\Practices	'*Council sees that as an issue. That's why we're trialing things like permeable paving; we've got a site over at Oxford Terrace, where we're working with TREENET.*' - E - 6
81	Physical\Water\Practices	'*We've trialed water filled barriers, we've trialed permeable paving, we're trialing capturing it off the kerb. But you're only trialing for possibly a hundred trees or a couple of 100 trees. How long drought is this drought going to go for? We've got 23,000 trees we need to save. So I see that as one of the major challenges.* ' - E - 6
82	Physical\Water\Practices\Species selection	'*Again it comes down to your species selection.*' - O - 3
83	Physical\Water\Practices\Regime	'*Ideally its 2-3 years currently. They have done some trials putting in those water rings. Looking at different soil additives.*' - O - 3
84	Physical\Water\Practices\Regime	' *So Council's method is water truck. And that's certainly a major recurrent expense-and it's difficult to secure that sort of recurrent funding.*' - O - 3
85	Physical\Water\Practices\Regime	'*Water is also becoming a big problem. We try to water all our new trees for 4 years to aid in establishment. In the first year 3 times a week, then, if all is going well, the second year twice a week and the third and fourth year once a week, depending on how they are performing. We are finding its becoming increasingly difficult to maintain the water levels up to what they require. Establishment is a problem and success rate is dropping*' - W - 5
86	Physical\Water\Practices\Irrigation systems	'*We've had options where planting's been in private ownership, and a common irrigation system passes through several ownerships. And then when you have got an issue with the irrigation supply, then that effects everything. Someone put a fence up and you realize that nothings being watered anymore. So Council's method is water truck. And that's certainly a major recurrent expense-and it's difficult to secure that sort of recurrent funding.* ' - O - 3
87	Physical\Species selection\General	'*The species of trees that we plant. And the management then thereof – like pruning, maintenance.*' - E - 1
88	Physical\Species selection\General	'*Tree species-has been an issue. Especially if changing a tree from the existing species.*' - E - 2
89	Physical\Species selection\General	'*Species choice and selection.*' - W - 3
90	Physical\Species selection\Past decisions	' *Probably historic decisions, of tree species being planted, has caused some issues. Which needs to be balanced, when you think back what was there in that time when the tree was planted. Certainly some of the species that were planted, when you go out there, with a 30-40 year old tree, you think, yes, a better decision could have been made.* *We have issues with sideroxylon in Kensington, Norwood area.* ' - E - 5
91	Physical\Species	'*I suppose in this area its mainly the situation of the past actions. So it's*

	selection\Past decisions	*inappropriate species within street environments-where we have Eucalyptus sideroxylon or Eucalyptus camaldulensis planted in verges. In verges where we have a fairly average width of about 3 metres with a footpath offset of a minimum of 1.5 metres. So by the time you install a kerb and channel down one side, and a footpath down the other side of the tree, it doesn't leave much room for the tree environment.* ' - O - 4
92	Physical\Species selection\Past decisions	'*Golden Grove is simply poor tree selection.* ' - O - 5
93	Physical\Species selection\Past decisions	'*Back in the late 70's, early 80's the Council at the time was a very progressive Council .They made a decision at the time that every street in Unley that could be planted with street trees would be planted with street trees. So within 3 years from the late 70's to early 80's every street in Unley was planted with street trees. Now probably one of the problems with that quite a few decisions were made on the run. Quite a few selections that were inappropriate species Quite a few selections that at the time were Schedule B trees under the Sewers Act that turned into Schedule C-not to be planted in the streets. So we had to deal with those.*' - E - 6
94	Physical\Species selection\Past decisions	'*So a lot of trees that we've continued to have problems with over the years, stuff like Eucalyptus sideroxylon. We used them as street tree plantings back then and since found we've got problems with the management of them. One of the problems with sideroxylons is that they get included bark, bifurcation, problems with splitting and things like that*' - E - 6
95	Physical\Species selection\Drought climate	'*Jacarandas are difficult to grow now. Why? Changing climate?*' - E - 2
96	Physical\Species selection\Limited selection	'*There is a limited tree species selection.*' - W - 1
97	Physical\Species selection\Perfect tree	'*There is no perfect tree species.*' - W - 1
98	Physical\Species selection\Perfect tree	'*Unfortunately there is no such thing as a perfect street tree, wish there was.* ' - W - 3
99	Physical\Species selection\Natives	'*We are trying to push the native agenda, we have a commitment to try and plant natives- but our species list is not totally native. Still a perceived notion out there that natives are ugly and problematic.*' - W - 3
100	Physical\Species selection\Natives	'*The other thing with trees we are both aware of and we are back up against, you get themes. Energy? are doing most of the work around here on big projects and it's a cut and paste between sites. So the street trees they are selecting are the same trees everywhere. One site is abutting rural land, open grassy woodland country. And they are whacking in Claret Ash and Pyrus and stuff. It's not appropriate, its cut and paste between different sites. It's got to relate to the surrounding environment. Getting back to Richard the engineer and the Sim's road thing and he said we can have natives. I said it's not just native/non-native, its whether it's appropriate for the character and amenity of the area, not just within the boundaries of the site, it's how it fits within the amenity for the broader area, I don't care if its native from another area. People just have this divide, if you don't want exotics then you want endemic locals. But it's not that. A bit of creativity and a bit of variation, not Pyrus everywhere.*' - O - 6
101	Physical\Species selection\Risk	'*In the last 5 years it's more of a litigious society-litter and fruit drop-particularly with the Queensland Box.*' - E - 5
102	Physical\Species selection\Longevity	'*Golden Grove is simply poor tree selection. I think trees were selected on a theme, rather than longevity. So its fine, the trees have got 20 years. They look good. But 20 years is not enough for a tree. I reckon you need a kind of design criteria for a street tree. And 20 years is still a good wicket, given all your car impacts and oil and all those sorts of things. But I think if you looked at their design lifespan, I think you'd go their design life was 10 years. And we should be aiming for like 40 years. You're going to build this subdivision, here's the top 10 things you have to do, and one is to get 40 years out of your street trees. Because when you add up all the cost of them. The bigger they are the more benefits they provide.*' - O - 5

103	Physical\Species selection\Preferred species	'*Things like your Tuckeroos, I think Burnside's planting a lot of Tuckeroos, which are a tropical, and the supplier will tell you they can grow 2m in one year, when they're young. They're becoming popular and they survived the 45 degree sun as well the other day.*' - O - 5
104	Physical\Species selection\Resident pref	'*Some people are unhappy with the species that's chosen. You will never please everybody, and this is why we have to have a Street Tree Manual, because everybody's got a different opinion on what's a nice tree. There are restrictions on what is commercially available, which dictates that.* ' - W - 4
105	Physical\Species selection\Root barriers	'*We are getting more and more requests for root barriers and things like that to stop tree roots going in there-which is not ideal either, cutting roots, but otherwise it ends up as a liability issue. No one has come up, to my knowledge, with a good outcome. Trees are smart aren't they. It depends on the quality of the root barrier-it will push the roots down, and I guess visually they won't be there. But as I said there's no silver bullet, so you have to do what you can with what you've got. We generally put the root boundary on the fence, property line.* ' - W - 4
106	Physical\Succession planning	'*A lot of our trees are getting old. It's a bit different up here because we've got little townships. Not all our township have street trees. And then a lot of the developed areas don't have street tree planting either- its more people's gardens go right out to the kerbs.*' - E - 1
107	Physical\Succession planning	'*A lot of our trees were planted 20-30 years ago and so now are getting to the stage where they might be getting to the end of their lifespan. So that's a problem that we will face down the track.*' - O - 1
108	Human\Anti tree attitudes\General	'*Community response is probably one of the problems.*' - W - 3
109	Human\Anti tree attitudes\General	'*And as a consequence of providing this service the community appreciates the look of the streetscape. Displays some ownership and protects it. It varies and in some areas the residents protect it passionately, in other areas we've got a job and a half to get the streetscape to grow and develop because of the extensive vandalism or lack of ownership.* ' - W - 6
110	Human\Anti tree attitudes\General	' *We don't have those political issues around trees like in Burnside. In some of the newer areas I think there is a little more awareness around that. And it's very case specific, it really depends on that relationship with developers.*' - O - 3
111	Human\Anti tree attitudes\General	'*Street trees stir up the emotions, a lot of people want them and some don't.*' - W - 5
112	Human\Anti tree attitudes\Litter	'*I personally I don't see any problems but the main issue we have is leaf litter.*' - E - 3
113	Human\Anti tree attitudes\Litter	'*The maintenance costs around their house. Sweeping up leaves, roots coming in and taking water from their gardens.* ' - E - 4
114	Human\Anti tree attitudes\Litter	'*In the last 5 years it's more of a litigious society-litter and fruit drop-particularly with the Queensland Box.*' - E - 5
115	Human\Anti tree attitudes\Litter	'*Maintenance considerations can be an issue-leaf litter, limb drop, which can also be a safety issue.*' - O - 2
116	Human\Anti tree attitudes\Litter	'*Its interesting thinking through the botany of trees in relation to the concerns people saying they are having. One big concern is the perceived mess of trees-flowers, leaf, branch drop.*' - O - 4
117	Human\Anti tree attitudes\Litter	'*I had a letter yesterday where someone was complaining about everything under the sun, especially these accursed trees that drop blue flowers at the moment, Jacarandas of course. And I know certain residents who will ring up every year at this time complaining about the tree in their street. So it's trying to deal with that. Trying to actually get people to accept the fact that these tree as wonderful things, and just because you've got one at your house that drops leaves, there's no need to carry on about it. And they all drop leaves, we know that. They always think their tree drops more than everyone else's tree.*' - E - 7
118	Human\Anti tree attitudes\Litter	'*The other problem I have, this will sound strange, is the residents. Residents like trees, but they seem to have a passion for disliking the tree*

		that's in front of their house. Because things drop leaves you see. And every tree has got problem, or a fault, or a branch that's fallen, or something like that. And it always seems to be the tree in front of their house, never the neighbour's tree. And trying to keep them happy.' - E - 7
119	Human\Anti tree attitudes\Aged pop	'*My ultimate goal, as Manger of Parks and Gardens, is probably to have a living tree in front of every single residential and business property in the Council area. Now that's hard to achieve because in some of the areas where we've got an ageing population, people these days are very loathe to have a tree in front of their property. They say it draws moisture from their lawn, the leaves drop on their lawn, and they are too old to rake them up now.* ' - W - 6
120	Human\Anti tree attitudes\Aged pop	'*If you look at the complaints coming through the city here, it's that older generation that are house proud, and tidying up the trees mess has got beyond them. They make the comment that council doesn't think about us. To some extent that is true, but the other side of the coin is council has to consider future generations. One resident who is 80 years old recently complained she had never had a tree and didn't want one now. She doesn't want the tree because it is going to shade her property and would have to clean up after it.*' - O - 4
121	Human\Anti tree attitudes\Vandalism	'*The only problem is we can't get enough of them in the ground, and when we do they get vandalized. Especially some of our young stuff, we do have a vandalism problem. It makes it hard to establish, if you are trying to plant up an avenue, you are constantly going back. Even worse, when the tree's a nice size and you think it's OK, they come along and smash a mature tree after 2-3 years. That's pretty disheartening.*' - O - 1
122	Human\Anti tree attitudes\Vandalism	'*Just general vandalism, trees hit by cars. You can have a young tree, and get it going, but until they become a decent size. There goes 3 or 4 years of growing and you are back to a hole in the ground.*' - W - 4
123	Human\Anti tree attitudes\Vandalism	'*Development is a big problem. The increase in population into the area relates to an increase in vandalism.* ' - W - 5
124	Human\Anti tree attitudes\Property damage	'*.The perception of trees cracking houses, that's more prevalent now with the dry. It seems that we even have some engineers who use street trees as scapegoats. You look at it and think it's ridiculous, it's all to do with the soil type. We have the Bay of Biscay soils, which is an amazing soil that probably should have been left as market gardens.*' - E - 3
125	Human\Anti tree attitudes\Property damage	'*From my perspective working in the western suburbs, probably the perception and attitudes of the western suburbs to mainly medium to large trees adjacent to their properties, overhanging their properties.*' - W - 1
126	Human\Anti tree attitudes\Property damage	'*Last week we had another issue with a bloke who wanted two trees removed-because his lawn was dying, but the lawns dead because he doesn't water it, but he's blaming the trees.*' - O - 1
127	Human\Anti tree attitudes\Property damage	' *roots coming in and taking water from their gardens.* ' - E - 4
128	Human\Anti tree attitudes\Property damage	'*There's a real fear about trees and I believe its unfounded; however residents are often reluctant to have trees, especially gum trees, in front of their property. On the same residential development that is having the Spotted Gums planted the builders have said that the tree roots will grow under the house, and ruin the footings, so they will have to beef up the footings. They propose charging a 20% premium for the footings, because of gum trees planted out the front, which is absolutely ridiculous. The developers are now asking, hang on a minute, these gum trees, how safe are they? Apparently some people are pulling out of building contracts because their house costs have gone up 20%. I think the landscape architect is getting an arborists advice on that. I wouldn't have thought you would have an issue like that.*' - O - 2
129	Human\Anti tree attitudes\Liability	'*In our area it would be risk, so things like,* *-pavements, lifting of pavements* *-bushfire risk* ' - E - 1
130	Human\Anti tree attitudes\Liability	'*The biggest risk for us as a Council is the public liability risk-because we are required to provide a clear pedestrian footpath-and we put a living*

		element next to it which intrudes into the footpath causing trip hazards. A major headache and not an easy one to resolve. So its damage to infrastructure I suppose, damage which is caused by a living tree-root invasion, which ends up causing public liability issues.' - W - 2
131	Human\Anti tree attitudes\Liability	'*In the last 5 years it's more of a litigious society-litter and fruit drop-particularly with the Queensland Box.*' - E - 5
132	Human\Anti tree attitudes\Liability	'*Maintenance considerations can be an issue-leaf litter, limb drop, which can also be a safety issue.*' - O - 2
133	Human\Anti tree attitudes\Liability	'*There's one that I've missed out there and that's insurance companies. Queensland Box-a magnificent tree given enough moisture. But every Council in SA is trying to remove every Queensland Box they've got because their insurers are telling them they are a high risk because of the gum nuts.*' - E - 7
134	Human\Anti tree attitudes\Traffic accidents	'*Then you get your trees being blamed for causing traffic issues, when cars leave the road and things like that.*' - O - 4
135	Human\Anti tree attitudes\Perception of benefits	'*People don't see most of the benefits, they don't know most of the benefits, not consciously. They would if they were missing, if all the trees disappeared they would notice the loss. In terms of increased problems. People don't notice benefits, but they do notice the costs.*' - E - 4
136	Human\Anti tree attitudes\Perception of benefits	'*When they begin noticing problems, trees are perceived as a liability-a big problem.*' - E - 4
137	Human\Anti tree attitudes\Perception of benefits	'*Can't educate everyone about tree benefits-its too big and too hard, and I doubt people would believe us.*' - E - 4
138	Human\Anti tree attitudes\Perception of benefits	'*But do people need to understand the benefits? Not necessarily-most people don't care. I don't think so. People need to take it for granted to be honest. Do you know what goes into making a road, technically? Maintaining a road, how much of your rates goes to that? Most people don't care, just want to hop into their car and go down the road. It's the same with trees, they need to be able to take it for granted. But we need to manage it efficiently and optimally for them to take it for granted. But they need to begin respecting trees as being of value and the profession as being valuable and essential. If a council's doing its job properly all of the services should be taken for granted.*' - E - 4
139	Human\Anti tree attitudes\Perception of benefits	'*The other problem I have, this will sound strange, is the residents. Residents like trees, but they seem to have a passion for disliking the tree that's in front of their house. Because things drop leaves you see. And every tree has got problem, or a fault, or a branch that's fallen, or something like that. And it always seems to be the tree in front of their house, never the neighbour's tree. And trying to keep them happy.*' - E - 7
140	Human\Pro tree\Protective	'*The main issue. Reluctance to remove aged trees. Need to change people's perceptions of the removal of a tree and projection of what a new tree will look. People are reluctant to change. This has a lot to do with the reasons why they moved into the area. They did so because of the amenity, character of the streetscape. When that changes, it changes their basis for moving here.*' - E - 2
141	Human\Pro tree\Protective	'*Have always struggled with this. Prescott Terrace-had war memorial avenue issues, plus people in that street have come to expect that existing streetscape. If it changes in a short period of time it will be difficult for them to accept.* ' - E - 2
142	Human\Pro tree\Protective	'*Our residents see huge benefits. Very protective of the tree stock. There's very little we could get away with in relation to trees without it being picked up. We're very conscious of that, of how protective the residents are for the trees. You only need to remove a tree you haven't given notification to remove and you'll find out how unhappy they are.* ' - E - 6
143	Human\Pro tree\Protective	'*Our policy talks about, we have to give 2 weeks' notice to residents for the removal of trees-and that's to, I think 50m from the tree. So that's all locked up in our policy. So we certainly recognize the value of them.*' - E - 6
144	Organisational\Implementation	'*Apart from the services it's really the implementation-when is it happening, who's responsible, who's doing the consultation.*' - O - 3
145	Organisational\Implementation \Staff resources	'*Probably the only other problem with our street trees, it probably wasn't until back in February, when we actually started a full time arbor team.*

		Before that people would swap from team to team, and just act on customer requests. There was a period of time when there wasn't much maintenance done. And so it's become a bit reactive now, there's more trees being removed because of their poor structure. But now the guys are onto it. ' - O - 1
146	Organisational\Implementation \Cant plant enough	'*The only problem is we can't get enough of them in the ground, and when we do they get vandalized*' - O - 1
147	Organisational\Attitudinal\Planner attitudes	'*Planning just don't look at the trees as an issue-they just remove it. We're trying to hang onto as many as we can.*' - O - 1
148	Organisational\Attitudinal\Planner attitudes	'*We are slowly educating the planning to be mindful of these sort of things. Because once you take them out you obviously can't put them back anywhere else.* ' - O - 1
149	Organisational\Attitudinal\Planner attitudes	'*We are rewriting policies, and we are trying to maybe put a price on tree, then we can use that money to plant trees elsewhere. And obviously they are making a lot of money out of it, so hopefully we can go down that path as well.*' - O - 1
150	Organisational\Attitudinal\Planner attitudes	'*You can't just drill a hole anymore and pop a big tree in it. That's what Council expects you to do. That's the problem with engineers, they don't understand it. And that's a problem we have with engineers and planners, that when they design things they think that's it, when they build a road or a wall they can build it and walk away and not touch it for 20 years. But when you build something with landscaping, it's the start of a long process of maintenance. And it's hard for them to comprehend what the process is.*' - O - 1
151	Organisational\Attitudinal\Planner attitudes	'*But not enshrined in our planning procedures.* *It still is the last thing anyone thinks about with a new subdivision or a new project.* *We work with developers and say we will approve of that tree, but you've got to show us where your services are first.6 months later you find out where the services are and the sewer is right under where they want the trees. Then you get them in back down mode. As in we'll put in shrubs or something. The developers probably mean well, but just the processes don't work. And as an individual you can't change that.*' - O - 5
152	Organisational\Attitudinal\ Engineer attitudes	'*You can't just drill a hole anymore and pop a big tree in it. That's what Council expects you to do. That's the problem with engineers, they don't understand it. And that's a problem we have with engineers and planners, that when they design things they think that's it, when they build a road or a wall they can build it and walk away and not touch it for 20 years. But when you build something with landscaping, it's the start of a long process of maintenance. And it's hard for them to comprehend what the process is.*' - O - 1
153	Organisational\Attitudinal\ Engineer attitudes	'*We had an engineer the other day, a stormwater pit in the TPZ, sent him the conditional list. This engineer was going on, you can't tell me that digging within 1 m of the root zone is going to do any damage at all, and just wouldn't accept it. So I said you can't tell me if I change power points at home, and I'm not an electrician then it's going to be a problem, can you. If I'll be careful or not. He said that's different, I said why? You've got a rule and it's a rule, don't tell me.* ' - O - 6
154	Organisational\Attitudinal\ Engineer attitudes	'*One of the problems I have with all this-I'm in charge of the trees. I'm also in charge of the infrastructure. I'm also involved in risk management-so every Tim I do something I end up going home and talking to myself about it, saying well look at the risk you've created. You could end up doing nothing if you listened to all the disciplines.*' - E - 7
155	Organisational\Attitudinal\ Change resistance	'*A good example, we had one road in the area with a high crown, very deep old stone gutters, extremely high bluestone kerbing. You couldn't get out of the car unless you parked a metre or so out from the kerb. Our aim was to narrow the pavement down, give more room for the trees and rebuild the roadway. I just succeeded in narrowing it down and rebuilding it.. I didn't succeed in putting roundabouts in. They were just so negative to change. So I guess what I am saying is the exercize at Unley (Windsor Street) probably wouldn't work here, it would be far too radical for a lot of the residents.*' - E - 7
156	Organisational\Attitudinal\	'*But having said that, times have changed. And that project was 4 years*

	Change resistance	*ago. We actually irrigated reserves 4 years ago, we don't do that anymore and we don't get complaints about it. So maybe if I can sell the right way-I could come up with concept design that narrows the road down, allows for parking on one side, even if we rearrange the side on which the planting is, and incorporate within that some sort of retention/detention of water. It would be a winner.*' - E - 7
157	Organisational\Attitudinal\ Change resistance	'*But again it has to be in a style that is consistent with the character of the area. That's tough.*' - E - 7
158	Organisational\Attitudinal\ Change resistance	'*The problem I've found here is there's resistance to change.*' - E - 7

Street Tree Constraints

No.	Category	Commentary text
1	Comment	' *So community and space.*' - E - 4
2	Comment	'*I think a lot of the similar stuff.*' - O - 2
3	Comment	'*Covered above I think.*' - W - 4
4	Physical\Local conditions\Coastal	'*Obviously location is a constraint for us as the coastal environment is obviously a lot harsher for street tree planting and establishment*' - W - 1
5	Physical\Local conditions\Soil	'*So Robert has a program where he rebuilds so many kilometres of roads each year as part of our Asset Management Plan-when they go out and do a condition rating on a road they take into consideration the soil type.. In the sand areas they may do a minimal amount of road reconstruction because in the sandy areas the roads have a life of probably 50-60 years at this stage. In the centre of the city they have a life of 40-50 years because they are on the stable soils. But in the eastern sector of our city, where you go past Hampstead Road the soils are more reactive and road pavement failure is more common. In this area which is towards the eastern boundary-the roads seem to have a very short lifespan, and as a consequence we've got more resources allocated to that area.*' - W - 6
6	Physical\Local conditions\Soil	'*But for us here at Tea Tree Gully the dry subsoil, it's almost like you should stop planting trees for 2 years.*' - O - 5
7	Physical\Local conditions\Soil	' *Soil can be a limiting factor at some locations but are not a very big problem at West Torrens - the preparation of an area is, which relates back to time and money.*' - W - 5
8	Physical\Local conditions\Soil\Compaction	'*And to some extent-compaction of soils-throughout the whole area.*' - W - 1
9	Physical\Local conditions\Soil\Compaction	'*Soil compaction in the vicinity of road and other civil/ earthworks is a persistent issue.*' - O - 2
10	Physical\Local conditions\Soil\Compaction	'*I guess there are things like compaction, the more popular the street ends up being, the more the trees are impacted upon. If you do create a nice shaded street that people do use more than another, and they park their cars under it because they get the shade, then it leads to compaction and the trees decline. Compaction's probably a key one.*' - O - 5
11	Physical\Local conditions\Climate	'*From our point of view its climatic local conditions. The Adelaide Plains is not as favourable for tree establishment. We have identified we have 6-8 weeks at most key planting time during the winter planting season. That's if it's a normal season that's favourable and wet*' - O - 4
12	Physical\Local conditions\Local character	'*I suppose up here, because of the character of the townships, we like to plant exotic trees. So it's not always appropriate to plant indigenous species. Because that's not the character of the area. So that's going to be a challenge for us probably. The push is for planting local species. Certainly we do advocate that in other areas.*' - E - 1
13	Physical\Local conditions\Local character	'*But for example Stirling Main Street-you can't convert to indigenous plants, because that's just not the character of the street. People come to see the English village style. It's a tourist attraction. So that's going to be a challenge.*' - E - 1
14	Physical\Local conditions\Development	'*We do not have a lot of greenfields sites like Salisbury, Onkaparinga, PAE-its more infill development in this area.* ' - E - 2
15	Physical\Local	'*We're not like hills face councils-our street tree network is going*

	conditions\Development	*through a transition of change and redevelopment. You look at the beautiful streetscape in the eastern suburbs-Tea Tree Gully, Playford, Campbelltown, Burnside, Onkaparinga and Salisbury, because they've got a lot of greenfields areas, their planning can give consideration to having more street tree planting, and it can be designed in such a way that doesn't affect adjacent infrastructure.*' - W - 6
16	Physical\Local conditions\Development	'*Some of the stuff they have done with their plantings is magnificent, but we don't have the room. Our Council area is very urbanized, and where we are not urbanized we are very commercial and industrial. We don't have as good opportunities as some of the other Council's. But that doesn't exclude us from trying to come up with ongoing ideas, and plans, and strategies.* ' - W - 6
17	Physical\Street space\Verge width	'*Probably space in the footpath.*' - E - 1
18	Physical\Street space\Verge width	'*The area available for planting.*' - W - 2
19	Physical\Street space\Verge width	'*The lack of space in verges for planting is a particular problem.*' - O - 2
20	Physical\Street space\Verge width	'*So I guess the biggest constraint is providing enough space to get the tree to grow successfully. I think we can get them to grow reasonably, to keep them alive but it's a matter of how can you get them to grow them to be excellent specimens. Get them to maturity.*' - E - 6
21	Physical\Street space\Verge width	'*Money…Apart from narrow verges, however, in most cases you can accommodate a tree if you had more funds to create better planting areas. We establish a 1.5 metre walkway at the sacrifice of trees. I think there should be more leeway where we can accommodate both. Engineers have rules and regulations that they try to adhere too but at times it is at the expense of the street tree, again.* ' - W - 5
22	Physical\Street space\Verge width	'*In some cases you only have 1.0 metre or less to work with. Older areas like Thebarton or Mile End just can't accommodate that 1.5m pathway and a tree.*' - W - 5
23	Physical\Street space\Verge width	'*More money and appropriately allocated room must be addressed.*' - W - 5
24	Physical\Street space\Constraints	'*For example in Woodside there's lots of verandahs and things like that so you can't really put a tree in the footpath-you only end up with half dozen. You need to put them in the road.*' - E - 1
25	Physical\Street space\Constraints	'*The power lines is one of the issues mentioned before.*' - E - 1
26	Physical\Street space\Constraints	'*Also the liability placed on Council for a tree planted in the road. So many constraints.* *-road clearances* *-footpath clearances* *-overhead powerlines* ' - E - 2
27	Physical\Street space\Constraints	'*Availability of space and the implications/ burden placed on Council for all the services in the road reserve. In the past it seems Council ignored the presence of gas, water etc. Now they are fully aware of these constraints.*' - E - 2
28	Physical\Street space\Constraints	'*In some of our newer areas, before the developers planted the trees, we had real trouble with actually planting trees-because of the services, the footpaths and things like that, was a real constraint. In some areas you just couldn't plant trees. That just stopped us full stop.*' - O - 1
29	Physical\Street space\Constraints	'*Those conflicts*' - W - 3
30	Physical\Street space\Constraints	'*I would say these days all the infrastructure. By the time you get the underground services and above ground services.*' - E - 5
31	Physical\Street space\Constraints	'*Mainly infrastructure constraints. The amount of area we have got to work with, and trying to flip it around so the first thing that's thought of is, we need to get trees into this street, how are we going to design the road. We're on the way but still very much the last thing that's done is the arborists are asked to come in and plant trees, once the infrastructure works are finished.*' - E - 6

32	Physical\Street space\Constraints	'*We're getting there, working on it, lots of positive gains being made, but I don't think it will ever flip right around.* ' - E - 6
33	Physical\Street space\Constraints	'*The trees don't have a chance-if we follow the letter of the law. Which we obviously don't, because if we did the tree wouldn't exist.*' - E - 7
34	Physical\Street space\Constraints	'*Another detail from DTEI showing clearances-pruning, providing room in the carriageway, sight distance.*' - E - 7
35	Physical\Services	'*Other utilities and infrastructure-ETSA, SA Water, Telecom.*' - W - 2
36	Physical\Services	'*Especially services-power lines and the particular power service provider. Reluctant to sit down and get a good result for all concerned. A very fixed focus agenda whereas the benefits of trees are well proven. They seem to miss out when it comes to service provision.*' - W - 3
37	Physical\Services\Infr longevity	'*Longevity of civil infrastructure is another. We would love to turn it over our Water Insensitive Design streetscapes and make them water sensitive.* ' - E - 4
38	Physical\Services\Infr longevity	'*Realistically it can only happen over the normal lifespan of that infrastructure. Otherwise its wasteful, replacing infrastructure that doesn't need it.*' - E - 4
39	Physical\Services\Positives	'*So I think that's the main constraint, other than services. But it's not really a constraint to successful tree planting. Sometimes services lead to better planting. For example you might have a services problem, and have less space, but you might plant palms, and end up with a really god theme you hadn't thought of. Or you might have overhead powerlines, and the community wants them undergrounded because they want the trees, so the services being in there actually leads to an investment.*' - O - 5
40	Physical\Services\Positives	'*I've got a project right now, which is a new land division, where there's a sewer and I just think the best tree, a smaller Eucalypt might be better than a big tall one. And there's a services that's helping our argument. We know you want a big tall tree, and that's fine, it's probably a good spot for it, but it just isn't going to look right , it's not going to be the right impact because you've already got big trees around there.* ' - O - 5
41	Physical\Water\General	'*The obvious one is water.*' - E - 1
42	Physical\Water\General	'*At the moment that's the main thing.*' - E - 3
43	Physical\Water\General	'*Water's one.*' - W - 3
44	Physical\Water\Limitations\ Restrictions	'*And it's certainly a lot harder to get mains water, to get water meters and things like that, with SA Water changes in their regulations. So you need to justify why you are using mains water.*' - E - 1
45	Physical\Water\Limitations\ Drought	'*What's becoming more apparent now is the ability to water during times of drought stress and very limited soil moisture. There's just no soil moisture in the ground any more. You dig a hole and its all dust. How do you charge that water, how do you get it down into the root zone?*' - O - 2
46	Physical\Water\Limitations\ Drought	'*And probably things like water, I guess water, the drought has become a constraint, because the soil profile is drying. But with good selection you can keep going. But for us here at Tea Tree Gully the dry subsoil, it's almost like you should stop planting trees for 2 years. That's what we are trying to do as an operational measure. We are trying to plan now and plant with the drought cycle season. And that's because our resources are stretched to the limit. As in 6 water trucks totally booked up, and if you want a water truck you've got to fight for it, because they are out there watering trees, and obviously dust.*' - O - 5
47	Physical\Water\Limitations\ Drought	'*But for us here at Tea Tree Gully the dry subsoil, it's almost like you should stop planting trees for 2 years.*' - O - 5
48	Physical\Water\Limitations\ Climate change	'*At the moment the climatic changes. Because all of our trees are watered on bore water. I noticed that they tick along for a while, but with the weather pattern we've been having I think the water's starting to get quite salty. Especially near the end of last year we had a few trees that ticked away and then all of a sudden just died. I believe that possibly could be due to salt.* ' - E - 3
49	Physical\Water\Limitations\ Local climate	'*From our point of view its climatic local conditions. The Adelaide Plains is not as favourable for tree establishment. We have identified we have*

		6-8 weeks at most key planting time during the winter planting season. That's if it's a normal season that's favourable and wet.' - O - 4
50	Physical\Water\Limitations\ Local climate	'*In relation to existing groundwater, soil moisture and things like that for establishment. So that's obviously a big thing.*' - O - 4
51	Physical\Water\Limitations\ Establishment	'*Watering during establishment can be difficult under current water restrictions if no infrastructure for automatic irrigation is available as hand watering may be difficult to resource in time of high demand*' - O - 2
52	Physical\Water\Limitations\ Establishment	'*And the on-going water requirement for establishment-again that's very much related to species selection.*' - O - 3
53	Physical\Water\ Species choice	'*Its the choice of species-you need to pick the right species for the right area.*' - E - 1
54	Physical\Water\ Species choice	'*At the moment that's the main thing. Also just having a guide to what will survive the climate change if the climate keeps going that way. The street trees we are looking at, will they be long lived, do they have the adaptability to go with the changes. That's one thing that sits in the back of your mind. You are always trying to look at all the avenues so you don't repeat the sort of thing that happened in the 1970's, where you had inappropriate species planted, a lot of argy-bargy between the residents, Council, engineers when damage occurred.*' - E - 3
55	Physical\Water\Species choice	' *We need to be more cognizant of drought tolerant or water conservation type species.*' - E - 5
56	Physical\Water\Species choice	'*And the on-going water requirement for establishment-again that's very much related to species selection.*' - O - 3
57	Physical\Water\Species choice	'*But with good selection you can keep going.*' - O - 5
58	Physical\Water\Adaptation	'*And I don't think I would go into water issues, and the climate change thing. Trees are highly adaptable. It's a matter of, as a street tree industry, or as a local government, we need to let people know that dryer climate, climate change makes it harder to plant trees. And everyone's going to believe you, but we need that backed up with some science and things like you are doing.*' - O - 5
59	Physical\Water\Adaptation	'*There was a funny one with Greenhill Road trees. Unley Council just put out a press release. The trees are half dead, you don't have to be an expert to see that. But Unley Council's got an agreement to maintain them, mow the grass and look after the trees. Which is typical, we do that for Delfin for Golden Grove. We've said we value the streetscapes so much we'll look after them, not allow DOT to do it. That's what Unley's done, but now the trees are dying. The Department of Transport told them to turn the water off, to meet water restrictions. And ACC is going to provide recycled water from the sewerage treatment plant. But it's like, you've got 3 land mangers now and trees are dead. So you're going to have to get your act together. So that's a threat to the future of street trees. Nothing's going to ever happen there. That can't be a good solution to a main road. I think that's a really good example. And you might say, oh it's the wrong trees, but its different to Golden Grove. They are elms that would have made it through the drought, no problem, if they were just getting water for keeping the grass green. I think it's John Lamb who's been putting out a lot of advice on tree watering, they don't necessarily want deep watering, its where the feeder roots are, and every trees feeder roots are in a different spot. And an elm is pretty tough, they just need a bit of care at the feeder level. Thinking about it, they are more important because they are associated with the parklands. And with major commercial, high profile businesses that generate wealth and employment for all of Adelaide.*' - O - 5
60	Physical\Water\Adaptation\ Stop planting	'*But for us here at Tea Tree Gully the dry subsoil, it's almost like you should stop planting trees for 2 years. That's what we are trying to do as an operational measure. We are trying to plan now and plant with the drought cycle season.*' - O - 5
61	Tree stock\Quality	'*Stock selection to me, if I had more time put I'd be putting more effort into that.*' - E - 7
62	Tree stock\Quality	'*You know I continually get told, we have good stock this year, and I go across and look at it before they plant it. And you wouldn't give it to your worst enemy to plant in their front garden, it's not good enough.*

		Traditionally around now I'll send a customer request to the depot saying I want the stock selection to take place. It's already taken place last year and the suppliers know what we want and supposedly it's there. I just want to go and make sure they check over Xmas to ensure the stocks ready. If I had more time I would be chasing them, saying that's no good, send it back. Some years its good, some years we get good selection.' - E - 7
63	Development\Urban infill\Densification	'*We do not have a lot of greenfields sites like Salisbury, Onkaparinga, PAE-its more infill development in this area.* ' - E - 2
64	Development\Urban infill\Crossovers	'*Plus the nature of Burnside. We have large property sizes, and values, so there has been a huge increase in the number of land divisions, and as a result more driveways and an increased number of service outlets. You get double the number of crossovers, water meters, stormwater outlets, gas, electricity, sewer etc.*' - E - 2
65	Development\Urban infill\Frontages	'*For example, with a 25m frontage , you would get an18-20m m clear zone for possible street tree planting. Now you are more likely to get only 5-10 m of space available for street tree planting.* ' - E - 2
66	Development\Urban infill\Greening implications	'*Space and population-as the population becomes more dense we need more greenery for those benefits. But as the population gets more dense there's more pressure on space, more difficult to grow trees. So community and space.*' - E - 4
67	Development\Urban infill\Greening implications	'*If urban consolidation was planned better, then you might have more linear parks in a consolidated suburb, that become your street trees, even though they are not in the street.*' - O - 5
68	Development\Urban infill\Greening implications	'*That just isn't really marketable, with the small land divisions.*' - O - 5
69	Development\Urban infill\Greening implications	'*So that's definitely a real one in Tea Tree Gully.*' - O - 5
70	Development\Urban infill\Greening implications\Planning	'*For us its urban consolidation. And that's more so because it's not planned. There's no plan really where urban consolidation should occur in Tea Tree Gully.*' - O - 5
71	Development\Urban infill\Greening implications\Planning	'*Its allotment based. And if front it ends up being in front of 3 street trees, then they will go. And that's just because it's completely market driven. Urban consolidation is still market driven. If our Council has got a one tree per house policy, and the frontage gets half as narrow we get twice as many trees. but they'll be twice as hard to manage.*' - O - 5
72	Development\New subdivision\Tree damage	'*New developments are becoming equally as difficult. Developers create wonderful looking areas with lovely green trees and lush vegetation beneath them - the problem is they establish them within the early stages of development, and then the builders come along and trash them. Vehicles drive over garden beds, through trees and shrubs simply because the roads are not wide enough to accommodate the larger vehicles trying to service the area. Underdale has been a nightmare. Builders will not take responsibility.*' - W - 5
73	Development\New subdivision\Lack of control	'*It sounds like Playford takes the position the trees are Council's. Other Councils like Onkaparinga, the developer does it and we take over. And we probably take that approach. So it's hard to control the soil analysis, they might be planting on fill. And you don't really know what you are doing. And it's just coming in waves. So you might sit for a year and it's no land divisions, then all of a sudden they want to do 100 streets, and they've done no research. They haven't really thought about designing with the landscape.*' - O - 5
74	Development\New subdivision\Cost	'*The developer sees, whatever size the subdivision, $2000 in topsoil analysis, no we're not going to do that. Even that amount they won't see as being productive. We're only paying $10,000 for the trees. It's a cost benefit thing. But if they actually talked to the people they're selling the land to, and the future community, and looked at their needs. They would realize that it was a good investment. And for us to go out as a Council, and analyze, with the Street Tree Master Plan, I don't think that would get to that level. It would provide you with a guide, but a good street tree planting needs the experts to go out and look.*' - O - 5

75	Development\New subdivision\Cost	'*So I think that's the main constraint, other than services*' - O - 5
76	Human\Community attitudes	'*The main constraint is also the main motivator-the community. Support varies across the whole community and we need to manage the community as a unit. Some sections of the community are really pro-tree, others sections are not as pro tree. Council works under one policy, so you can't do enough for some areas and too much, stop it, in others.*' - O - 4
77	Human\Illegal removal	'*Willingness of residents to accept a street tree-you can have trees bonded and get developers to put them in, but there's still no way that you are able to stop residents from physically removing them. And it does happen.*' - O - 3
78	Human\Illegal removal	'*The other issue in relation to establishment is the actions of others, with vandalism, tree removal, removal of trees just because they can do so.*' - O - 4
79	Human\Litter	' *People's requests for non-fruit bearing, or leaf littering.*' - E - 5
80	Human\Succession planning	'*Another big constraint, residents can be-especially when it comes to 2nd generation tree planting. Lack of education by residents that don't understand. Residents tend to live in their street for the moment, so they're constantly thinking property values, what's their property worth. Whether they don't understand, or don't want to understand that trees have a life cycle-they reach maturity, and then they go into decline. We've got many streets in Unley with the trees in decline. If we went and tried to remove them now we would get hung. We've got streets out there with Cedars for example that if you looked at the individual trees on a tree by tree basis you would probably recommend that every one come out. But when you look at them as a whole, as an avenue down the street, they look fine.*' - E - 6
81	Human\Succession planning	'*A good example I keep using, a street called Ferguson Ave at Myrtle Bank-its got white cedars and just about every tree in that section of the street is hollow and in really poor condition, just like the trees along Greenhill Road, the elm trees growing in the central median-currently looking at what we can do about those. Currently hollow and in poor condition, but if we went in there and said we are going to pull all of these out, and start a replacement program. What we've found `is that where the residents have given us permission to do that, we've had some really successful 2nd generation tree planting programs. We had a street in Clarence Park with E. torquata, we had a huge problem trying to get them removed, but if you spoke to those residents in that street now, once they've been in nearly 10 years you wonder what all the fuss was about. It's a beautiful street, even though they're not native, Pyrus, they look magnificent. But what people see is what will happen to their property values if the trees come out-scorched earth approach. The challenge there is we have to do it sympathetically which quite often means that you've got to stage removals, stage over years so you get trees developing at different rates, different heights. On most occasions when people object to the removal process they end up going to Council, Council will look for a win-win situation, and usually the win-win situation is that they will stage the removal. Which is not always the best solution to create a new streetscape.*' - E - 6
82	Organisational\Resources\General	'*Resources, and knowledge, and standards.*' - O - 6
83	Organisational\Resources\Funding\Budget	'*Budget.*' - E - 1
84	Organisational\Resources\Funding\Budget	'*With respect to support for urban tree planting at the strategic level. We don't have a problem with that. We get great support from our strategic policy unit, senior staff, elected members. It's never been an issue. Being such a big Council we are pretty well funded. The funds are there-to date I've never had funds cut for any of the tree planting programs, tree maintenance programs which is very encouraging.*' - W - 6
85	Organisational\Resources\Funding\Best practices	Money…Apart from narrow verges, however, in most cases you can accommodate a tree if you had more funds to create better planting areas.

86	Organisational\Resources\Funding\Best practices	'*The constraints of the cost to put in other treatments for footpath, kerb and gutter which are very restrictive.* ' - W - 2
87	Organisational\Resources\Funding\Best practices	'*So a bucket full of money would be good. Wide footpaths, big trees, rubber footpaths That's an example putting rubber format footpaths, but its double the price of block paving. I've done a couple since I've been here. We're talking $100/sq m vs. $40/sq m.*' - W - 2
88	Organisational\Resources\Funding\Best practices	' *Dollars. If we become wealthy as a nation we could turn over infrastructure in a few years. I don't think that would be wise or sustainable. Better things we could do with the money-re-grow forests.*' - E - 4
89	Organisational\Resources\Funding\Best practices	'*Money…Apart from narrow verges, however, in most cases you can accommodate a tree if you had more funds to create better planting areas.* ' - W - 5
90	Organisational\Resources\Funding\Best practices	'*More money and appropriately allocated room must be addressed*' - W - 5
91	Organisational\Resources\Funding\Best practices	'*Soil can be a limiting factor at some locations but are not a very big problem at West Torrens - the preparation of an area is, which relates back to time and money.*' - W - 5
92	Organisational\Resources\Funding\Other	'*And that's because our resources are stretched to the limit. As in 6 water trucks totally booked up, and if you want a water truck you've got to fight for it, because they are out there watering trees, and obviously dust.* ' - O - 5
93	Organisational\Resources\Staff\Staff levels	'*Internal resources. Just the maintenance requirements. We are trying to play catch up to understand what we have out there and need to maintain and look after, and therefore in the future replace or plan for replacement.*' - W - 3
94	Organisational\Resources\Staff\Staff levels	'*One thing we may look at is actually contracting out the tree planting-but then that has its own pitfalls too.*' - E - 7
95	Organisational\Resources\Staff\Skills\Consistency	'*Also for us having consistency between staff-potentially a constraint.*' - W - 1
96	Organisational\Resources\Staff\Skills\Expertise	'*It not like a larger Council where you have a team who do the same thing every year. We have a changing workforce, they are multi-skilled and therefore not specialists in one area and its difficult to keep them up to speed.*' - E - 7
97	Organisational\Resources\Staff\Skills\Education	'*Most people planting a tree have some idea, but best practices are not always followed.* *And that changes over time. The gardeners here are still planting drain coil, it happens elsewhere too, which is now recognised as not being good. I guess they are still doing it because at that time of their training it was what was done. Copycat stuff. It depends, if it's in the hole right in the root ball it's not good. If it's not around the rootball its different. It's that old hangover copycat thing, if the Council next door is doing it. A short length right next to the brand new rootball dries it out. It depends how big the hole is, with a small hole you won't get much water into it. by. Get maybe 5-10 litres into the drain coil, it won't gravitate into the soil, most of it will gravitate into the macropores and evaporate out of the pipe. And once its finished evaporating it starts drying the soil out .It impairs trees if it's not used properly. You do see drain coil where they have used in conjunction with a tree trench where the water is being piped into it like a reservoir.* ' - O - 6
98	Organisational\Resources\Staff\Skills\Education	'*One of the problems I do have is staff-it's a problem I've got that is my own making. Because I just haven't had time to educate our staff. In tree selection, planting methods, watering methods*' - E - 7
99	Organisational\Resources\Staff\Skills\Specialist skills	'*Probably in the past Council's staff expertise-we're starting to employ more specialist people now. In the past there wasn't landscape architects here, there weren't qualified engineers, there weren't qualified arborists and horticulturists. That's been an issue in the past.*' - E - 1
100	Organisational\Resources\Staff\Skills\Specifications	'*Providing and developing specifications and people having access to them.*' - W - 1
101	Organisational\Resources\Staff\Skills\Specifications	'*In the procedure I've gone into a fair bit of detail on how I want trees planted. I think if someone else had written it and given it to them they probably would have followed it. But I just don't have time to push that*

		one any further. But it's a big concern to me. ' - E - 7
102	Organisational\Resources\Staff \Reduced planting	'*We have a staffing problem as well. So we used to try and plant as many trees as we can, but we could never manage or maintain them. So about 5, 6 or 7 years ago we pulled back on our tree planting, because we never had the resources to manage them. So we reverted back to virtually replacements. It got to the stage that we couldn't even water them to keep them through their first summer.*' - O - 1
103	Organisational\Strategic\ Strategies	'*And probably having those appropriate strategies in place.*' - E - 5
104	Organisational\Strategic\ Timing	'*Timing is a fundamental issue.*' - O - 3
105	Organisational\Strategic\ Priorities	'*Mainly infrastructure constraints. The amount of area we have got to work with, and trying to flip it around so the first thing that's thought of is, we need to get trees into this street, how are we going to design the road. We're on the way but still very much the last thing that's done is the arborists are asked to come in and plant trees, once the infrastructure works are finished.*' - E - 6
106	Organisational\Strategic\ Priorities	'*We're getting there, working on it, lots of positive gains being made, but I don't think it will ever flip right around.*' - E - 6
107	Externalities\State govt policy	'*Government policy. State and federal, mainly State planning policies can resolve these issues but State government doesn't appreciate the benefits of trees anywhere near enough. I'm not speaking about individual trees, protection of individual trees is short term at best, will die one day. The total urban forest. Old school planners-the planners know best. Have so many constraints thrown at them.*' - E - 4
108	Externalities\Devpt industry	'*The development lobby and business lobby advocating growth. Pretty powerful-money speaks. Trees are not getting the profile they need. In the US business lobby is starting to learn about the value of trees. They can get more dollars into their shop from further afield at a greener shopping centre. Need that US knowledge getting out locally, at the developers seminars. Need to do it in such a way that it doesn't detract from what they see as important, which is how many cars can we fit in this carpark. If we can engineer a space below the carpark we can create a shady carpark and if that can equate to a 20 percent increase in business they will do it. Would make a difference-two carparks on either side of the road, one you can park in the shade, one you can't, where would you go?*' - E - 4

Threats to Street Trees

No	Heading	Commentary text
1	Comment\Still plant trees	'*To be honest I don't see there is any threat to tree planting in the future. Its policy in this Council, that won't change. The trees may change, the species you use. There may be a push back to native trees. I think we've tried them in a way and they don't make good street trees unfortunately. So I can't really see going back to that. As far as I can see tree planting will continue. Dead trees will be replaced with new ones. I've yet to see any street come up and say we don't want trees.*' - W - 4
2	Comment\None	'*I hope there are none.*' - W - 3
3	Physical\Development\General	'*Further development.*' - E - 5
4	Physical\Development\General\ Space	'*I'd say again development-reducing planting space, planting opportunities.*' - W - 1
5	Physical\Development\Urban infill	'*Infill development.*' - E - 2
6	Physical\Development\Urban infill	'*Infill is probably going to be the biggest threat.*' - O - 1
7	Physical\Development\Urban infill	'*Urban infill, or the way it is going at least. Splitting single blocks into two, with double driveways reducing space to plant street trees. Coupled with that, streetscape is becoming the only place where trees can grow, or at least there's the opportunity for them to grow.*' - W - 3
8	Physical\Development\Urban infill	'*I think there is an issue with the subdivision of blocks. There's no*

		doubt about it, it's usually the tree that will suffer in something like this. Although it shouldn't be because that same developer will say to you they'd rather see trees in front of it. But just when they are building it. I consider that a threat in an older suburb like this. You wouldn't get that in the newer suburbs as they are planning around that. In Prospect, they want to encourage people to move into Prospect. And as I said there are a lot of big old blocks. That to me would be the number one issue for street trees. They are under pressure to get that through planning. Its more rates.' - W - 4
9	Physical\Development\Urban infill	'*The big point I see there is in relation to urban infill. The consolidation of built form.*' - O - 4
10	Physical\Development\Urban infill	'*Smaller frontages. In older suburbs where we planted 1-2 trees per front of property, that gets subdivided down the middle.*' - O - 4
11	Physical\Development\Urban infill	'*Inevitably when they go to put in a new driveway, when its subdivided, the existing trees are in the location of the driveway. So by the time they put a 3.5m driveway in for the property across a small frontage, with two properties, you haven't got much room left to plant a tree. You are losing a number of trees per street.*' - O - 4
12	Physical\Development\Urban infill	'*And then the location of driveways, and stormwater outlets, doesn't usually coincide.* ' - O - 4
13	Physical\Development\Urban infill	'*Urban consolidation is the biggest threat. Especially for a city that is somewhat established. With gentrification you have that loss. The person who sold the house was usually of the older generation who valued that tree in front of their property and took the time to care for it. The residents/ occupants who move in are usually not so concerned beyond their front fence so to speak, of the street environment.*' - O - 4
14	Physical\Development\Urban infill	'*Urban consolidation is going to be a really big problem.*' - W - 5
15	Physical\Development\Urban infill\Imp surfaces	'*Urban infill-which means more built up areas, with paved areas with stormwater-which results in water not permeating into the soil profile.* ' - W - 2
16	Physical\Development\Urban infill\Implications	'*Conversely- the type and style of property development now where private open space is getting smaller. This shifts the burden onto Council to create the urban form, urban environment etc.*' - E - 2
17	Physical\Development\Urban infill\Implications	'*And its part of the government's 20/20 strategy to increase population through urban infill. So we've got that conflict coming in and we're trying to say, with the street tree, and they want big leafy green streets, how do you do that when you've got urban infill and you've got narrow footpaths.*' - W - 2
18	Physical\Development\Urban infill\Implications	'*Urban infill, or the way it is going at least. Splitting single blocks into two, with double driveways reducing space to plant street trees. Coupled with that, streetscape is becoming the only place where trees can grow, or at least there's the opportunity for them to grow.*' - W - 3
19	Physical\Development\Urban infill\Implications	'*I would personally like to see increased density in key locations such as transport hubs. But coupled with that there still needs to be provision for greening.*' - W - 3
20	Physical\Development\New subdivisions\Verge width	'*I think residential subdivision design, with narrow verges, is one of the biggest issues.*' - O - 2
21	Physical\Development\New subdivisions\Verge width	'*With increasing urban development comes small blocks with narrow verges to get maximum block yield for the developers.*' - O - 2
22	Physical\Development\New subdivisions\Verge width	'*And for establishment of new areas its very much configuration of the road reserves, footpaths, verge, street widths.*' - O - 3
23	Physical\Development\New subdivisions\Verge width	'*And the width of the verge itself has reduced. The road space now is seen as being a minimal thing. Developers try to maximize the size of the lots and squash the road and try and condense everything into a smaller footprint. Then trying to install the required range of infrastructure, from a developer's point of view, or from a provision point of view, stormwater, power, sewer, electricity, everything else, in a new subdivision tends to be underground, as well as a footpath on top of the ground. It doesn't leave much opportunity in a verge width of approximately 2m, and that's it.*' - O - 4

24	Physical\Development\New subdivisions\Footpath location	'*Its also important where you put the footpath. I understand that Council has a preference for a major road to have the footpath at the property boundary, so you've got planting established between the footpath and the kerb, to give a better environment for pedestrians, which can allow for trees to be established in that zone if there is enough space. On smaller streets the footpath is usually at the back of kerb and residents generally tend to take up the space from their boundary to the edge of the footpath, which is fine because then they will look after it. The thing is if you have got a street tree in there and residents don't like the tree, you will find the trees tend to die.*' - O - 2
25	Physical\Development\New subdivisions\Footpath location	'*On the other hand if the footpath is on the property boundary, you get an alienated piece of land between the back of kerb and footpath. Council can't afford to maintain these areas, it can end up being too much, and the residents generally don't look after it because it's not theirs, so it just ends up being overlooked. Putting the footpath at back of kerb seems to be the best solution in residential streets from a general maintenance viewpoint but relies on residents accepting street trees in (effectively) their front yard.*' - O - 2
26	Physical\Development\New subdivisions\Tree damage	'*I believe the trouble often is that street trees are installed just after the road and civil works is completed, and before the houses are even finished, so they tend to get trashed during construction.*' - O - 2
27	Physical\Development\New subdivisions\Tree damage	'*Developers do want to install trees up front from a marketing point of view. It shows that they are actually conscious of it. But the issue is when you sell a lot and it gets built on 12-18 months after it is sold, you get construction traffic running around it, and you then do not have to wonder why half of them don't survive.* ' - O - 4
28	Physical\Development\New subdivisions\Tree damage	'*The contractors see the verge as theirs, and if there is a tree in the road, then it's not big so it doesn't matter.*' - O - 4
29	Physical\Development\New subdivisions\Tree damage\Bonding	' *In the past trees have not been bonded, it's something we've discussed that we would like to implement over the next couple of years.* *All the legal advice you get is you can't, yes you can take a small fee but it doesn't end up substituting for the cost of what it does to replace and maintain a street tree.* ' - O - 4
30	Physical\Space	'*Again, pressure on space.*' - E - 4
31	Physical\Space	'*And the constraints of room. It's an interesting one. We've tried to design around the tree, and not through the tree. We tried with a couple of street designs recently-we had plenty of pavement to play with. And what we tried to do was create areas that we could plant. But change is a terrible thing and they just did not want to do it. I could not convince them about the merits of what we were trying to achieve. That was North Walkerville, one in Medindie too. Big wide streets. Traditionally we have 11m wide roadways-and I tried to reduce those by 1-2 m, just to give the street trees an extra 1m on each side if I can. Most times they accept that, but if I go too far, I'm in trouble, they always want to have lots of parking on street and 2 way movement of traffic.*' - E - 7
32	Physical\Space	'*No room-that is the biggest issue.*' - E - 7
33	Physical\Infrastructure\Competition	'*Infrastructure competing with trees.*' - W - 1
34	Physical\Infrastructure\Repair	'*Infrastructure, also maintenance-repairs, reinstatement is a threat to maintaining good health and establishing trees.*' - W - 1
35	Physical\Infrastructure\Repair	'*For us in Charles Sturt, we predominantly have a verge of 1.5m so we've got a fairly restricted space. Some of them can even be 900-1200mm, that's what we're up against with WSP. And to undertake any reinstatement work for infrastructure, say kerb and gutter, it's not only the kerb and gutter it's the base for it, during that excavation period, that has an impact. Because their specifications indicate that they need 300mm behind the back of kerb of compacted fill-and in some cases it has been quite detrimental damaging tree roots, damaging trees in general. But I have to give*

		it to the engineering department, when it comes to larger trees where we do get involved, trying to have the ability to trial new practices and new materials' - W - 1
36	Physical\Water\Restrictions	'*And just having the availability of water.*' - E - 3
37	Physical\Water\Restrictions	'*So that's probably the two main issues that come to mind.*' - E - 3
38	Physical\Water\Restrictions	'*Water availability and restrictions.*' - W - 1
39	Physical\Water\Restrictions	'*Its making sure you allow sufficient room for the tree to grow unimpeded and doesn't have that interaction with the adjacent infrastructure. This also takes into consideration the canopy development of the tree. Because in the new areas they're building smaller roads, they're having shorter frontages on properties. So you can't plant a tree that's got a big strong canopy, because you are going to have it sitting on people's verandahs, and they want us there every five minutes to cut them back. So we have to be mindful that where we have these changes in urban design and construction, that we cater for the respective setbacks and so on.*' - W - 6
40	Physical\Water\Restrictions	'*The water is a huge issue-with the tightening of water restrictions over the last few years people are not watering their front gardens. People are very loathe to even lean over the fence to give the tree a bucket of water while its developing. That's a huge threat on the ongoing future development of trees. People used to water nature strips, and the grass areas their side of the fence. I think that moisture in a lot of instances got to the trees. Well that's been excluded from the equation and the trees are suffering.*' - W - 6
41	Physical\Water\Restrictions	'*One of the challenge in the future is the SA Water restrictions. We're currently at enhanced level 3. I think they will always allow tree watering to occur. But not being able to water some of the reserves-those trees are used to a certain amount of water being applied around that base area and the root plate, it's just not getting that supplementary watering. So we are looking at mulching off extensive areas to protect certain trees.* ' - W - 6
42	Physical\Water\Restrictions	'*I gave a paper at the roads conference in Port Lincoln on the impact of water restrictions on local government, and most of the impact I think is around the urban forest. I think unless trees can get water they are potentially at threat.*' - E - 6
43	Physical\Water\Restrictions	'*Probably the biggest threat as I see it is the water restriction issue. Finding supplementary water for trees.*' - E - 6
44	Physical\Water\Restrictions	'*I tend to think that water restrictions are here to stay.*' - E - 6
45	Physical\Water\Drought	'*Drought conditions.*' - E - 2
46	Physical\Water\Drought	'*Essentially we don't water trees after establishment in the Council area, however the prolonged drought may change that as mature trees are an expensive asset to replace.* ' - O - 2
47	Physical\Water\Drought	'*Drought of course. We have a lot of Golden Rain trees that were planted in the 1940's that in the last 2-3 years have gone into decline rapidly-dying within 2 years. You might notice the odd branch dying off, and that used to be the case in some of the old ones. It used to be after 10 years that you would take it out, now its 2 years. Once they start to go, it's very quick now.*' - E - 7
48	Physical\Water\Climate change	'*I would say climate change is the big one.*' - E - 3
49	Physical\Water\Climate change	'*And then what are our weather patterns going to do? With the dry weather trees will obviously be a bit more brittle and not be able to handle the wind so much.*' - E - 3
50	Physical\Water\Climate change	'*So that's probably the two main issues that come to mind.*' - E - 3
51	Physical\Water\Climate change	'*Drought. Climate change it is. Its climate change and the drought is a result of climate change. Which results in a larger volume of tree stock dying, mature trees dying.*' - W - 2
52	Physical\Water\Climate change	'*Water restrictions and climate change-just until trees established. We have access to bores for tree watering tankers. Couldn't use mains water. Less of an issue where looking at WSUD.*' - E - 4
53	Physical\Water\Climate change	'*Rising temperatures are a big concern. 3-4 degrees temperature rise on pavement is going to kill root growth in surface layers. Going to need to design better insulated surfaces. Permeable*

		paving with increased aggregate depth below it to get roots to grow deeper, will insulate it more, and have access to more moisture. ' - E - 4
54	Physical\Water\Climate change	'*Again with the established trees its monitoring of the potential water requirement, given climate change.*' - O - 3
55	Physical\Water\Climate change	'*And the climatic conditions you have to take into account. The selection of trees to install is quite limited if the future trends are taken into account.*' - O - 4
56	Physical\Water\Climate change	'*Climate change first and foremost-you can see some real issues starting to pop up.*' - E - 7
57	Physical\Water\Climate change	'*Trees we have planted and which survived well a decade ago are now starting to be an issue-only minor but you can see what's happening.*' - E - 7
58	Physical\Water\Climate change	'*Increase in global temperatures-we've seen the effects of that already. If that is going to continue it will be even more difficult to establish our urban forest.*' - W - 5
59	Physical\Water\Climate change\Opportunity	'*Then of course the unknown of climate change is something. Which might be in favour of trees? A reverse shift, being optimistic about it. If we start losing a lot of big trees round the place, we may realize we need to invest more in replacing them, we need to put more money into getting water out, keeping them going. Especially newer plantings, if they see the losses. The risk is you are going to lose those big old red gums and stuff in the landscape. But they will be the indicators that make them panic and put money into other trees.*' - O - 6
60	Physical\Water\Mature trees	'*And it's not just the new ones ,what we have got to worry about is the older trees.*' - E - 3
61	Physical\Water\Mature trees	'*We lost a few when we had that heat wave last year. A number of those trees were probably 50 plus years in age. You could see them slowly, slowly lose condition and they just couldn't cope, and just shut down. It was bizarre, almost like someone put a lethal injection in.*' - E - 3
62	Physical\Water\Mature trees	'*Drought. Climate change it is. Its climate change and the drought is a result of climate change. Which results in a larger volume of tree stock dying, mature trees dying.*' - W - 2
63	Physical\Water\Mature trees	'*Then of course the unknown of climate change is something. Which might be in favour of trees? A reverse shift, being optimistic about it. If we start losing a lot of big trees round the place, we may realize we need to invest more in replacing them, we need to put more money into getting water out, keeping them going. Especially newer plantings, if they see the losses. The risk is you are going to lose those big old red gums and stuff in the landscape. But they will be the indicators that make them panic and put money into other trees.*' - O - 6
64	Physical\Water\Mature trees	'*Essentially we don't water trees after establishment in the Council area, however the prolonged drought may change that as mature trees are an expensive asset to replace.* ' - O - 2
65	Physical\Water\Mature trees	'*Again with the established trees its monitoring of the potential water requirement, given climate change.*' - O - 3
66	Physical\Water\Mature trees	'*Drought of course. We have a lot of Golden Rain trees that were planted in the 1940's that in the last 2-3 years have gone into decline rapidly-dying within 2 years. You might notice the odd branch dying off, and that used to be the case in some of the old ones. It used to be after 10 years that you would take it out, now its 2 years. Once they start to go, it's very quick now.*' - E - 7
67	Physical\Water\Mature trees	'*Trees we have planted and which survived well a decade ago are now starting to be an issue-only minor but you can see what's happening.*' - E - 7
68	Physical\Water\Species selection	'*And the climatic conditions you have to take into account. The selection of trees to install is quite limited if the future trends are taken into account.*' - O - 4
69	Physical\Water\Species selection	'*So one of the challenges or threats is to find trees that can grow in that climate change environment. It will be very much the challenge for people like TREENET.*

		The trend was in the late 70's when we planted up our streets that we planted mainly natives, natives were very much the theme of the day. Then we've gone through a stage when almost all our residents request were non-native species. What we're finding now it's going back towards native species. So the problem we've got is finding suitable native species that will grow in the type of environments we're asking them to grow in. Current anecdotal evidence tells us that the trees we are losing due to drought and water restrictions-many of those are our native trees.' - E - 6
70	Physical\Water\Species selection	'*Trees that are surviving are trees like Jacarandas.*' - E - 6
71	Physical\Water\Species selection	'*It seems to me that the natives, once they go from lack of water they just go and can be dead from lack of water in just 2 weeks. Whereas some of the European trees tend to slowly go and you can give them a good drink and they will almost come back. A lot of that is anecdotal-haven't kept data on it.*' - E - 6
72	Physical\Water\Species selection	'*A lot of the trees we planted were WA goldfield trees-not SA. That's one of the problems-we would like to plant some indigenous indigenous plants, but finding any that are suitable and won't wreck your infrastructure. That go grow like a golden rain tree or Jacaranda can-its very difficult to find. When we select a native we are very much selecting select your WA torquatas, your Queensland box from Queensland-you've got to ask how suitable they are? I think one of the challenges there is for people like TREENET to come up with lists of trees that are suitable.*' - E - 6
73	Physical\Water\Species selection	'*Quite often trials can take quite a few years before you can say yes that's going to work. The question then is have we got the time to wait?*' - E - 6
74	Physical\Soil degradation	'*Soil degradation over time-we're seeing it now. In some areas of Adelaide rising salinity is becoming a concern.*' - E - 4
75	Physical\Species diversity	'*The other would be if a disease comes out that effects Manchurian pears! We seem to plant a lot of them-the tree that's in vogue at the moment.*' - O - 1
76	Physical\Species diversity	'*Hopefully in the future we can sort out new areas by developers planting the species and type we want. We've got a couple of big subdivisions about to happen in the next couple of years, so hopefully we can sort those out.*' - O - 1
77	Human\Nuisance\Intolerance	'*I think people becoming less tolerant of the inconveniences caused by trees. People are less tolerant than they used to be. They used to see the benefits as long as the tree was not overhanging their boundary. Now they complain if the tree encroaches on boundary or sucks up water from their front yard? They are less tolerant of leaf litter.* ' - E - 2
78	Human\Nuisance\Ageing population	'*Burnside has an ageing population, one of highest in the State. We have to be aware of the potential liability associated with street trees in the future.* ' - E - 2
79	Human\Nuisance\Species	'*This also has implications for tree species selection-trees can't have hard nuts or berries. We don't plant brush boxes or white cedars anymore. Tim Johnson is planting low fruit bearing cedars, we would like to also but can't take the risk.* ' - E - 2
80	Human\Nuisance\Illegal removal	'*Its also important where you put the footpath. I understand that Council has a preference for a major road to have the footpath at the property boundary, so you've got planting established between the footpath and the kerb, to give a better environment for pedestrians, which can allow for trees to be established in that zone if there is enough space. On smaller streets the footpath is usually at the back of kerb and residents generally tend to take up the space from their boundary to the edge of the footpath, which is fine because then they will look after it. The thing is if you have got a street tree in there and residents don't like the tree, you will find*

		the trees tend to die.' - O - 2
81	Human\Nuisance\Illegal removal	'*There was an incidence down Aldinga way where trees kept mysteriously dying in front of houses where residents had objected to having trees in front of their house. North facing with no eaves, why wouldn't you want a tree there?* - O - 2
82	Human\Liability risk\Liability	'*Burnside has an ageing population, one of highest in the State. We have to be aware of the potential liability associated with street trees in the future.* ' - E - 2
83	Human\Liability risk\Liability	'*What will the effect be in the future? Liability issues are important to Council. It may be too hard for Council to plant trees, so they won't do it. It won't happen in this Council though. The character of whole area would change. Council couldn't afford to let it happen.*' - E - 2
84	Human\Liability risk\Liability	'*Risk assessment-is a pretty hot topic for us within Council.*' - W - 1
85	Human\Liability risk\Fear	'*Fear of trees is a big threat to street trees also. I recently had a phone call from a resident who objected to having a gum tree in front of their place. In a small subdivision of 60 lots, with a nice northerly aspect overlooking Pedlar Creek the resident didn't want a gum tree in front of their block, they wanted another (exotic) tree. I explained that street trees are the same species, that's what street trees are about, to get a uniform character. I'm not sure they were convinced and driving through the development recently, which is still under construction, I noticed the tree is no longer there.* ' - O - 2
86	Human\Benefits not recognised	'*Will increase property values? People don't understand how it can happen, unless they go into an area with established tree cover and see the effect. I grew up in Marion, where they were loathe to put in street trees, and usually planted plums. Went back there a year ago-Council has done some street tree planting and used some decent tree species. It has changed the whole amenity of that street. Portrayed it as a higher class area,*' - E - 2
87	Human\Benefits not recognised	'*Residents will never come and say-you have done street tree planting badly, so carbon sequestration will be bad. They will only notice that it looks horrible. If you do it well it looks great also.*' - E - 2
88	Human\Benefits not recognized	'*Recognition of trees as an important part of the streetscape.*' - E - 5
89	Human\Benefits not recognized	'*Maybe a lack of education too, a lack of awareness of the importance of trees, is a limiting factor and a lack of awareness of the investment in trees, in time. It takes a long time for a tree to grow. If we start to lose the big trees in our parks and reserves as a result of this sort of drought, we've lost those trees for a generation; you won't replace those trees in a lifetime. So it's a big investment to lose, an investment in time.*' - O - 2
90	Organisational\Planning process\Priority	'*People's mindsets, in terms of planning, trees generally come at the end of that planning process. Probably built in up front rather than as add-on.*' - E - 5
91	Organisational\Planning process\Engineering	'*Stringent, uninventive engineering techniques-insistence on using inflexible materials (such as concrete) to channel water into the Gulf is ridiculous.*' - W - 5
92	Organisational\Planning process\Collaboration	'*Properly training people in the workforce generally, from a maintenance perspective, and also a planning perspective. Having those people with appropriate backgrounds involved in the up-front planning process.*' - E - 5
93	Organisational\Management\Budgets	'*Management costs.*' - E - 2
94	Organisational\Management\Budgets	'*Accountants. Don't recognize the value and costs of getting trees to a standard where they provide a benefit.*' - O - 6
95	Organisational\Management\Budgets	'*You want the budget cut, what do you cut? You won't cut something an engineer says is a legal requirement. You won't cut IT, everyone's sold on the idea that's what you have to do. You cut trees, and maintenance.*' - O - 6
96	Organisational\Management\Pruning	'*Appropriate pruning practices.*' - E - 5
97	Organisational\Management\Training	'*Properly training people in the workforce generally, from a maintenance perspective, and also a planning perspective. Having*

those people with appropriate backgrounds involved in the up-front planning process.' - E - 5

Most Viable Practices

No	Category	Commentary text
1	Comment	' *Hopefully these little bits and pieces build up for good results for the tree.* ' - E - 3
2	Comment	'*I can't really comment much about Holdfast being here for only a short period.*' - W - 2
3	Comment	'*Its probably what we are proposing to do.*' - W - 3
4	Comment	'*Not a lot.*' - O - 6
5	Comment	' *Getting it right.* ' - O - 6
6	Comment	'*With regards to the latest trend in tree planting-we're an active member of TREENET. We work extensively with the information available from that group-taking into consideration the species selection, the sustainability, longevity, the growth patterns of trees. We take all that into consideration. And the criteria for all of that-we also make sure that people who do the work within our Council area, namely developers, that they adhere to that.*' - W - 6
7	Comment	'*All those things in your paper.*' - E - 6
8	Design\Streetscape\Extent\Limited	'*And that's probably about it really because we haven't done a lot of street tree planting projects as yet. So the main street of Woodside is the only one that's been done since I've been here-which is 3 years.*' - E - 1
9	Design\Streetscape\Extent\Limited	'*Streetscape design, at this stage hasn't progressed to the reworking the street environment to address infrastructure impact. It's been discussed but hasn't got to that point that we have actually seen it. There is talk of it moving forward for future developments, but to what extent it gets picked up will be interesting to see.*' - O - 4
10	Design\Streetscape\Extent\Limited	'*Innovative streetscape design, that's a good one too.*' - O - 5
11	Design\Streetscape\Extent\Limited	'*In our Council, I think we do lack that innovation. Obviously we try, we know a lot of the techniques and things like that. But we are still trying to keep up doing it the normal way.*' - O - 5
12	Design\Streetscape\Extent\Limited	'*I think it will come, but it tends to be based on where the land division is, if it's on the River Torrens they will do the right thing. But as soon as it's not thee they will just resort back to the old way of doing it. That's with using site runoff, and things like that, to deep water the trees rather than Council having to provide extra water.*' - O - 5
13	Design\Streetscape\Extent\Change resistance	'*But change is a terrible thing and they just did not want to do it. I could not convince them about the merits of what we were trying to achieve. That was North Walkerville, one in Medindie too. Big wide streets. Traditionally we have 11m wide roadways-and I tried to reduce those by 1-2 m, just to give the street trees an extra 1m on each side if I can. Most times they accept that, but if I go too far, I'm in trouble, they always want to have lots of parking on street and 2 way movement of traffic*' - E - 7
14	Design\Streetscape\Extent\Change resistance	'*But there are a couple of options coming up where I really want to tackle it a little differently.*' - E - 7
15	Design\Streetscape\Space\General	'*Provision of maximum available space.*' - E - 2
16	Design\Streetscape\Space\General	'*And I think a lot of Council's in years gone by, when*

		they looked at a street they just looked at the street and the available planting room. But what we also look at too is the architecture of the streetscape.' - W - 6
17	Design\Streetscape\Space\General	'*And the constraints of room. It's an interesting one. We've tried to design around the tree, and not through the tree. We tried with a couple of street designs recently-we had plenty of pavement to play with. And what we tried to do was create areas that we could plant.*' - E - 7
18	Design\Streetscape\Space\Engineering	'*Engineers need to relook at back lanes etc. They don't need to be designed to highway standards.* ' - E - 2
19	Design\Streetscape\Space\Engineering	'*Getting things into specifications again, I keep nagging the engineers to make sure verges are wide enough because what's the point of having underground power then putting in small trees because your verges aren't big enough to have a big tree. You are losing your opportunity to have avenues of bigger trees.*' - O - 6
20	Design\Streetscape\Space\Subdivision	'*And space, to allow more trees you need more space. And that's what developers don't want to give you, as space is money. We need to plan areas of space for trees in these developments. The Divine site. Blocks are too small so we will probably go back through planning and say can you change that block into a reserve.* ' - O - 6
21	Design\Streetscape\Space\Subdivision	'*But once again one of the problems that we are encountering with Oakden is because of the short setbacks of the properties, sometimes we have conflicts with residents, with vegetation over their boundary and into their property.*' - W - 6
22	Design\Streetscape\Space\Verge	'*But one of the problems is the people that made that plant selection, 25-30 years ago was that the available planting room from back of kerb to footpath was only 900 mm. Whereas now we try and have a minimum area allocated for the planting of a tree. And that's something we have to negotiate with individual residents, businesses or developers.* ' - W - 6
23	Design\Streetscape\Space\Verge	'*Like in the new areas, where its generally 8m from kerb to kerb. The overall road reserve boundary is 14.8m. So you've got from back of kerb to footpath you may have available planting room of say 1.6m.*' - W - 6
24	Design\Streetscape\Space\Verge	'*Generally what we try to do with trees is never go closer than 1.3m behind kerb, and hopefully we've got a similar distance allowed from the tree to the footpath. And that allows the tree room to develop, to girth-up.* ' - W - 6
25	Design\Streetscape\Space\Verge	'*Infrastructure design. To date we haven't done a great deal, apart from the fact that we've tried at every opportunity when we redo kerb and gutter, to bring it in-to widen the verge. We've got a few really interesting examples of a verge between the edge of the path and the kerb, which would be 300-400mm. and we've got Pyrus, we've got Golden Rain planted in that gap. Which is just madness. We are taking those out when we get a chance and putting in Crepe Myrtles-a hardy, drought tolerant, attractive plant.*' - E - 7

26	Design\Streetscape\Space\Rd narrowing	'*Road narrowing is one of the issues we are looking at, at present. The streetscape program.*' - E - 6
27	Design\Streetscape\Space\Rd narrowing	'*Up in Myrtle Bank we are taking some trees out and want to put some back in. The opportunities there for narrowing. That's Whitecliff Street, taking out some E. sideroxylons, some of them significant. They're big trees and it's a small street-so there's the opportunity to narrow the street, bring the kerb in.* ' - E - 6
28	Design\Streetscape\Space\Rd narrowing	'*They are old roads, that have had their day, and need to be reshaped. They are probably in reality far too wide, which is great because it gives us scope to do something. So if you want to reduce it down to a fairly narrow roadway, you can create, probably in some cases an extra 3-4m of space on one side. Then you've got scope to do some amazing things in terms of tree planting, water retention, all sorts of interesting exercises.*' - E - 7
29	Design\Streetscape\Space\Rd narrowing	'*Just to give you an example, this is at Medindie, we have to do The Avenue, Arthur and Herbert. This is interesting. Kerb to kerb 14.5m, absolutely massive. So on the western side we have pitched stone kerbing and gutter which we'll keep. The crown of the road is probably1-2m in from the kerb-so you've got a fairly significant cross-fall to the other side. Power lines are low voltage on that side. We don't need 14.5m. We could drop that down to 9m, 9.5m-and it still gives them 2 way traffic plus parking bays both sides. That gives me scope to widen the footpath on the other side and create a verge that we can put decent trees into. And the other option is to try and capture runoff water from the top right through as the next step. That gets into the swale. It's a very formal street so it has to be done carefully. And if I come in far enough we could shift the street lighting out onto the edge which would be very interesting as well. You really have to streetscape this and create something interesting.*' - E - 7
30	Design\Streetscape\Space\Rd narrowing	'*This is Landsdowne Terrace-really wide, 11.5m wide. I have to do some drainage works and put new drain right through the centre or the side of it. And again I've got a 4.5m footpath. I could probably squeeze this down to 9.5m. So that gives me currently 2m spare, so I can convert this 5 into a 7, and do something with that, even have a good look at water retention. And I can put stormwater below this area-and then I can capture surface water and when those areas fill up it drains back into the stormwater system. And you create the perfect environment for street trees. Once again these are good because I've got room. It's a road that runs from all the way from NE Road down to the river. So its long. And there will be scope amongst this for traffic control treatments, and I'll make sure I plant them with as much as I can. So the aim of this one is to crowd it with trees to the point where it really is a picture. The real aim if I can achieve it is to get points where the carriageway is down to 6m in width, two 3m lanes. And plant trees either side with the objective of the crowns joining above.*' - E - 7
31	Design\Streetscape\Space\Footpath locn	'*We put a footpath down and that delineates Council land. I think you don't need a footpath both sides, you can have a footpath on one side and the other side you could put your tree where the footpath is, giving it*

		room to grow. Then you've got the problem of people wanting to cross the road. Then you don't have the possibility of heave and just squashing them into the little nature strip.' - E - 3
32	Design\Streetscape\Space\Trees in road	'*With Woodside that was putting the trees in the roadway. Which has caused other issues-in terms of loss of parking, and difficulty of parking.* ' - E - 1
33	Design\Streetscape\Space\Trees in road	'*Innovative streetscape design is important. I don't think putting a tree in a parking bay is innovative, but in this Council they don't do it due to litigation concerns over conflict with traffic. A bollard is okay, which is really to protect the tree, but the tree is a no-no and that's what I'm worried about, that mind set. Planting a tree in the parking lane with a structural soil underneath but without kerbing makes good use of the space, plus you can collect stormwater from the water table.*' - O - 2
34	Design\Streetscape\Space\Trees in road	'*Options of putting trees within the road corridor.*' - O - 3
35	Design\Streetscape\Space\Ave alternatives	'*I like avenues, but I also like the idea of getting away from monoculture-because you end up with the same problem throughout. But I also like to have iconic points where you can get that specimen tree that needs that space and really dominate the streetscape. The reason I like that is we just don't have the scope or the space to actually put in an avenue of big trees, let's go for smallish trees that give you the feel of the street, but every so often have a kerb extension and put in something decent. We actually did that on Robe Terrace to a degree. And they've all lived surprisingly. We've got Pyrus, and Planes. And they haven't really started to dominate the streetscape yet. I'm looking forward to that because they seem to coexist beautifully.*' - E - 7
36	Design\Streetscape\Space\Borrowed landscape	'*We are starting to look at whether we can use that borrowed landscape idea, so planting in private property rather than on the footpath.*' - E - 1
37	Design\Streetscape\Siting\Conflicts	' *It's making sure that the cross-section meets the best outcomes for the development of the tree and minimum damage to adjacent infrastructure.*' - W - 6
38	Design\Streetscape\Siting\Conflicts	'*And I guess it's to eliminate planting in inappropriate places where its impractical.*' - W - 4
39	Design\Streetscape\Siting\Conflicts	'*What I didn't mention, previous practices of planting the wrong tree in the wrong spot. Trees too close together. Now 10-20 years down the track you have got these trees growing to their full maturity, and causing exactly these problems, of lifting kerbs. But you can't undo what's been done. You can only put a plan for what you are going to do in the future. That's basically what we are trying to do here. Those Eucalyptus spathulata, we used to have a lot around here, now we are down to a few. I think because they are a WA tree. Now they are in clay soils, holding more moisture, and these are going into it, when normally they would be in a sandy type soil without much moisture. Horrendous.*' - W - 4
40	Design\Streetscape\Siting\Guidelines	'*There's a Public Works utilities handbook. Rob Tiggemann our chief engineer, swears by this handbook. The handbook outlines recommendations for minimum distance we should be allowing for tree planting. We try and ensure that's what we use. Everything we do is in accordance with a council developed specification. Generally we like a nature strip to be a minimum of 2.6m and this is supported*

		in that handbook. That handbook is something we try and hang our hat on because its accepted by the International Public Works Engineers Association. ' - W - 6
41	Design\Streetscape\Siting\Guidelines	' *And if we were to produce a full-blown street tree planting strategy, master plan we would have to have reference to that.* ' - W - 6
42	Design\Streetscape\Siting\Guidelines	'*I guess it's also the siting of trees, part of that manual is keeping trees at least 7 m apart. To allow them space to grow and to collect what water they can, above and beyond what we supply them.*' - W - 4
43	Design\Streetscape\Siting\Guidelines	'*But really, as far as siting, that's up to us on the ground, and you stick to the street tree manual, which is Council policy.*' - W - 4
44	Design\Streetscape\Siting\Guidelines	'*Another detail from DTEI showing clearances-pruning, providing room in the carriageway, sight distance.*' - E - 7
45	Design\Streetscape\Siting\Guidelines	'*The trees don't have a chance-if we follow the letter of the law. Which we obviously don't, because if we did the tree wouldn't exist.*' - E - 7
46	Design\Streetscape\Integration	'*There's a recent streetscape upgrade which involved trees and garden beds all up front. That worked very well across an engineering and horticultural staff skill set. Bennet St, a very narrow street in Stepney, and Well St.*' - E - 5
47	Design\Streetscape\Subdivision design	'*Because the way they design streets in a new subdivisions isn't innovative. No matter how you put it, it's the same way they did a subdivision 30 years ago, but the verges are narrower. Because services are more reliable-the pvc's and the conduits are all stronger, they all need less, you've got cameras to stick down there in holes and inspect things, so I think they've just squashed the verges, and that's the reason why. So I don't think they are being innovative. I guess the best example of innovative streetscapes is in West Torrens, with the UniSA development there. It's not your normal layout, and they've put all the street trees in first before the houses. Which isn't always a god idea, but, all the driveways are built, all the sewer connections, sewer goes down the middle of the roads. And they've got also your WSUD treatments, because they're on the River Torrens, a lot of it runs down the end of the street in swales that are planted and form part of the street tree system.*' - O - 5
48	Design\Streetscape\Subdivision design	'*The other one is the Aldinga Arts Eco Village, we did a little visit down there. We went, our gardeners would hate us, we would go broke with maintenance. But it looks fine and there's no cost burden to Council. And it's because they haven't got kerb, sealed bitumen for one way traffic. And short streets. A lot of turning bays.*' - O - 5
49	Design\Streetscape\Park	'*Try to plant. Conscious of the fact Council wants potential significant trees planted in the area . So we are tending to do more planting in our open space and parks where we're not going to have the same engineering conflicts we have in our streets. So you're talking Windsor Street and some of our larger parks.*' - E - 6
50	Design\Tree pits\Size	' *In the last couple of years our planting holes are wider. Before they were basically augered, a bit larger than container size, and they would have gone*

		deeper. So now we're going wider, but not excessively deeper. ' - W - 1
51	Design\Tree pits\Size	'*We generally over-excavate our holes to ensure the tree gets a good start. It's not always possible to do a pit 800x800x 900 deep because of services and other infrastructure, where you may use a standard, I think the guys are using a standard 750 auger at the moment. And then they soften off the sides, to break up the glazing so the roots can penetrate the walls of the freshly drilled hole.*' - W - 6
52	Design\Tree pits\Size	'*We may use root barriers, we may over-excavate areas. That also is given consideration.*' - W - 6
53	Design\Tree pits\Size	'*Tree pit size is a fundamental. The thing with the Brachychiton-the physical girth of that particular species is quite phenomenal. It's just allowing for that. And having a willingness with project managers, particularly around the civic building we built 3 or 4 years ago, that was quite a major project with a street, civic square, planting setout then all of a sudden we want to double the size of the tree pits. We are talking about Brachychiton not a normal tree trunk tree. And that created a bit of angst, with the servicing through there, plus part of the design is uplighting. So that was a great result-we were the client.*' - O - 3
54	Design\Tree pits\Size	'*Below ground space is something that has been implemented in certain areas across the city centre.*' - O - 4
55	Design\Tree pits\Size	'*Where possible we are extending our tree holes when we plant to get some more space.*' - E - 6
56	Design\Tree pits\Detail	'*Below ground, I used some of the stuff from a Treenet seminar a couple of years ago-I picked up a nice little booklet that is really interesting. It changed my thinking a little bit. The standard best practice tree planting detail.*' - E - 7
57	Design\Tree pits\Decompaction	'*I also encourage the Construction Team to de-compact the soil, not necessarily de compacting it deeply but more extensively as the trees tend to grow outwards, they don't tend to grow downwards as much as people think. Decompaction also assists with absorption of any rainfall or run-off penetrating in to the sub soil.*' - O - 2
58	Design\Tree pits\Contractors	'*And what we do once all our service locations are done, and we decide to move into a street, we've been using a contractor to dig the holes, and prepare the holes.*' - W - 6
59	Design\Tree pits\Trench	'*In certain areas structural soils, suspended pavements, root trenches. In the urban centres with footpaths from kerb to property basically.*' - W - 3
60	Design\Tree pits\Trench	'*Subsurface drainage, so individual tree pits might be linked. There's a cost implication.* *We are looking at trialing that in one of our civic precincts. Elizabeth Way-when I say trial we are looking at how much it is all going to cost. Tree root trenching we do a standard, we certainly ask for that. It's very much dependant on how wide the verge is. For our precinct along Elizabeth Way we will be bringing tree root protection all the way along footpaths. And back of kerb in some cases depending on where it's at.*' - O - 3
61	Design\Tree pits\Trench	'*And once again that's related to providing not only the drainage, but areas for roots to grow through sub-surface trenching. That will be underneath pavement.*

		I think this is more of an engineering solution for how those pavements are suspended. Fantastic if we could fit it in. This is just a small area within a square.' - O - 3
62	Design\Tree pits\Struct soil	'*Obviously TREENET's helped us too with contacts. I've spoken to David about SPACE soil. We used it a couple of years ago around one of our big trees in Gawler, and they paved around it, and it still seems to be working ok.*' - O - 1
63	Design\Tree pits\Struct soil	'*In certain areas structural soils, suspended pavements, root trenches. In the urban centres with footpaths from kerb to property basically.*' - W - 3
64	Design\Tree pits\Struct soil	'*I'm not a great fan of planting trees between 3-6m. I don't think they work long term. If you've got a purpose built area outside a big building in the city and you excavate a huge hole and put in a fantastic soil mix and watch it develop that's fine. But we just don't have the budgets to do that. I'm aware of David Lawry's space product. That's a purpose product for special environments, and anything that's as porous as that product it's going to be a winner because it can hold so much moisture.*' - W - 6
65	Design\Tree pits\Struct soil	'*And once again that's related to providing not only the drainage, but areas for roots to grow through sub-surface trenching. That will be underneath pavement. I think this is more of an engineering solution for how those pavements are suspended. Fantastic if we could fit it in. This is just a small area within a square.*' - O - 3
66	Design\Tree pits\Struct soil	'*I know we have below ground tree planting boxes in the main street of Mawson Lakes, with structural soils there so that they can establish trees in the high profile urban area down there.*' - O - 4
67	Design\Tree pits\Struct soil\Opposed	'*I'm not a great fan of planting trees between 3-6m. I don't think they work long term. If you've got a purpose built area outside a big building in the city and you excavate a huge hole and put in a fantastic soil mix and watch it develop that's fine. But we just don't have the budgets to do that. I'm aware of David Lawry's space product. That's a purpose product for special environments, and anything that's as porous as that product it's going to be a winner because it can hold so much moisture.*' - W - 6
68	Design\Tree pits\Root directors	'*John Street to some extent we've done with pits and root directors around the base of the trees of new plantings. Not that they have been over successful, I suppose because of the paved surfaces around the rest of it, and infiltration, permeability not being there.* ' - O - 4
69	Design\Tree pits\Root directors	'*Where we've put them in we've used root directors- the jury is out there, whether it's going to work or not. One of the streets nearby we put root directors in and planted standard Pyrus. And that worked reasonably well, the trees looked ok, damage to the kerbing is minimal. So I'm reasonably happy with the way that's worked. Because what they do now is they tend to lift the root director out of the ground. Most of the trees in the street have survived quite well without lifting. Just the odd one or two have caused problems. Of course the answer to that is you just grind top off the director.*' - E - 7
70	Design\Tree pits\Root directors	'*The use of porous paving and root directors, on some of our main thoroughfares, has proven to work favorably.*' - W - 5

71	Design\Tree pits\Root cells	'*We've just done a big project in the Main Street. If you drive down you will just see a couple of trees, but underground we actually dug some huge pits, and put in a block of cells. Arborgreen, we bought them through. And brought in some special soil, and built a structure underground for the trees to grow into. Underground there is a pit probably 6m long and 1.5m wide and 1.2m deep. So what's underground is to give the tree the best chance to grow in that situation. Because there used to be an old railway line down the centre of the road, so you can imagine the compaction over the years. So we had to do something, and we got a lot of conflict for it, because it was so expensive. When you drive down the road and see 4 trees costing thousands of dollars, they wonder what's going on. And we also had the root directors, cages. A lot of work went on below the ground, but no one sees that. When they write into the paper they just say the tree cost so many thousands of dollars. They don't realize the work to do it.*' - O - 1
72	Design\Tree pits\Root cells	'*We also used Arborgreen root directors in car park on 11th street. They built this car park, and had these little islands, and afterwards they said they would like some trees. Can we put them in these little islands? So we got them to dig out these islands and put in some root directors. And built cage around them. It was an afterthought, but it actually worked out quite well.*' - O - 1
73	Design\Infrastructure\Comment	'*The Council is in a unique position as we often undertake our own streetscape upgrades and I have the opportunity to work directly with the engineers and explore the options so I also get a good appreciation of the competing requirements for trees and infrastructure.*' - O - 2
74	Design\Infrastructure\Comment	'*Infrastructure planning and design. I'd like to say that is the case, but no.*' - O - 4
75	Design\Infrastructure\Hardscape\Design\Space	'*Provision of maximum available space.*' - E - 2
76	Design\Infrastructure\Hardscape\Design\Space	'*Engineers need to relook at back lanes etc. They don't need to be designed to highway standards.* ' - E - 2
77	Design\Infrastructure\Hardscape\Design\Space	'*What I didn't mention, previous practices of planting the wrong tree in the wrong spot. Trees too close together. Now 10-20 years down the track you have got these trees growing to their full maturity, and causing exactly these problems, of lifting kerbs. But you can't undo what's been done. You can only put a plan for what you are going to do in the future. That's basically what we are trying to do here. Those Eucalyptus spathulata, we used to have a lot around here, now we are down to a few. I think because they are a WA tree. Now they are in clay soils, holding more moisture, and these are going into it, when normally they would be in a sandy type soil without much moisture. Horrendous.*' - W - 4
78	Design\Infrastructure\Hardscape\Design\Space	'*Infrastructure design. To date we haven't done a great deal, apart from the fact that we've tried at every opportunity when we redo kerb and gutter, to bring it in-to widen the verge. We've got a few really interesting examples of a verge between the edge of the path and the kerb, which would be 300-400mm. and we've got Pyrus, we've got Golden Rain planted in that gap. Which is just madness. We are taking those out when we get a chance and putting in Crepe*

		Myrtles-a hardy, drought tolerant, attractive plant.' - E - 7
79	Design\Infrastructure\Hardscape\Design\Replacement	'*For infrastructure, now say there is a tree that's into the water table, we actually leave the kerbing out and either just run the bitumen in there or build a pseudo kerb and water table. Instead of having that mindset-we've got to put concrete down there. Very hard for the engineering guys, it's got to go in a straight line, it's going to get wet, get that root out. Don't bother, leave a space and come past it . You go out and look at it. The tree is probably 30 years old, it's done the predominant amount of growing. Now its key is survival, so you don't need to go entombing it, so to speak.*' - E - 3
80	Design\Infrastructure\Hardscape\Materials\Flexible	'*Looking at down the track doing further things like that-where we do have a tree that's worth retaining. In the case of a footpath that's been lifted we use rubber, the same sort of material they use at playgrounds. It's quite thick but malleable. We did some sections, I think 7 years ago, and it has slightly risen, but the rise isn't jagged, it's a sort of hump. It's a way to retain a tree, and not impact on cutting roots etc, and it is porous so you still get air and water exchange through the rubber. I will email you some photos with street names.* ' - E - 3
81	Design\Infrastructure\Hardscape\Materials\Flexible	'*Our engineering have used the rubberized compound in a couple of locations as an alternative material in footpaths.* ' - W - 1
82	Design\Infrastructure\Hardscape\Materials\Flexible	'*We've been trialing flexible pavements in a couple of areas with a significant tree that we want to retain. And they have ongoing problem with lifting the footpath.* *We installed a couple of those treatments in an attempt to,* *Stop the public liability issue of trip hazards.* *Give an area with some permeability to get a bit of water onto the trees*' - W - 2
83	Design\Infrastructure\Hardscape\Materials\Flexible	'*Across the road from St Peters Woodlands. We also put in there a rubber kerb and gutter. One of the issues with Norfolk Island Pines, the design is the tree's not actually in the footpath, it's between the footpath, and the kerb and water table. I think that's a reasonable design. We run the kerb behind the tree, with root invasion it can damage quite easily. So we put a rubber kerb around.*' - W - 2
84	Design\Infrastructure\Hardscape\Materials\Flexible	'*They reckon between 4-7 years that kerb breaks, and needs replacement, renewal. We will trial it, this is our trial plot. If it lasts 10-15 years its quite cost effective. And we put rubber footpath there. Trying to get that balance between the living element and the harder structures. We've also put rubble in there.*' - W - 2
85	Design\Infrastructure\Hardscape\Materials\Flexible	'*That's one of the main reasons we went to brick paving in lieu of concrete-because it will hump up and you can get away with that a lot longer before the pavers start to pop out.*' - E - 7
86	Design\Infrastructure\Hardscape\Materials\Flexible\Versus	'*Flexible pavements. I can't say we've tried anything at this stage. We are probably approaching it more from a perspective of when the tee fails we'll take it out an d replace with a more appropriate species. I know insurers don't like it. I've seen examples where they've taken a concrete footpath out and put in a*

		rubber mat arrangement, which works. But even I know when I go for a walk at night I can see the colour contrast between the black rubber and the white concrete. If you are not looking there's a change, and of course the tree is going to move the soil around, so there is a degree of risk associated with it.' - E - 7
87	Design\Infrastructure\Hardscape\Materials\Porous conc	'*With infrastructure planning and design, there has been initiatives, discussing with engineering to use alternative materials around trees. One example, it works quite well in a coastal environment, down at Henley Beach where there's sandy soil conditions. For the kerb and gutter upstand, where water was pooling because the Norfolk Island Pines had lifted the kerb and gutter. They have replaced it with a no fines concrete which gives water the opportunity to seep into the sandy soil. That's not a long term solution, but it's better than having water pooling where there would be complaints about that. It's at East Terrace, Henley Beach (the southern end)-the intention was to place no fines concrete right up to base of the trees. But after a bit o0f a discussion we were able to make them see reason that it's not ideal aesthetically, and also not to the benefits of mature Norfolk Island Pines.* ' - W - 1
88	Design\Infrastructure\Hardscape\Materials\Porous conc	'*West Torrens-have put in no fines concrete in a stretch of verge some 50 metres with small cut-outs with Plane trees. That's in Victoria Street just off Henley Beach Road, n the eastern side. Most of their verges are dolomite, and its u to the residents to have grass verges and maintain them. Aesthetically it's not too bad in comparison to the dolomite verges.*' - W - 1
89	Design\Infrastructure\Hardscape\Materials\RBG	'*We're also looking at Terrabond in a couple of locations-we've got a fair bit of damage around Hindmarsh stadium. That's been a bit of an ongoing problem. Plane trees were planted there. I think this one was a State government development, the Hindmarsh Soccer Stadium, so that the landscaping component came with it. So the Plane trees have caused a fair bit of infrastructure damage. So we are trying to deal with the damage with the intention of retaining the trees. And Terrabond has come up. It is expensive too. Concrete is one of the cheapest materials, or dolomite is. For a sealed surface concrete is for engineers. Rubberized compound is expensive. And I think Terrabond is a couple of hundred dollars a sq m.*' - W - 1
90	Design\Infrastructure\Services\Statutory	'*And when we do street tree plantings we try and ensure we comply with all the relevant statutory requirements and legislation. Our friends at ETSA- if they can unload work they certainly will. And I think we've got a responsibility in planting properly, correctly.*' - W - 6
91	Design\Infrastructure\Services\Statutory	'*And what we do once all our service locations are done, and we decide to move into a street, we've been using a contractor to dig the holes, and prepare the holes.*' - W - 6
92	Design\Infrastructure\Services\Locating	'*The other thing that's a huge impact on the street tree planting too, is the extensive resources required with preparing a street for planting. We go out and do full service locations-we have to take into account the usual- gas, electricity, water, sewer, and the*

		telecommunications infrastructure. And it's such an exhaustive process just getting the contractor to do that for you.' - W - 6
93	Design\Infrastructure\Services\ETSA	'*And also identifying those iconic trees-we've got an Oak tree in main street of Oakbank that in the past had a square cut out by ETSA around the power lines. So we're getting ETSA to be more sensitive pruning that particular tree.*' - E - 1
94	Design\Infrastructure\Services\ETSA	'*Here we've got fire risk categories, and they need something like 2m clearance or more. So it's like, you're pruning for 2 m clearance every year, some trees are never going to re-grow again and others will be back to the wire in 2 weeks. Some will never recover. You need to have tree types A, and tree types B and have a different clearances. That would be your starting point, whereas their contractors and their specifications are pretty much it's that. And otherwise you're going to get a bushfire. And that's wrong. Scientifically its wrong.* ' - O - 5
95	Design\Infrastructure\Services\Undergrounding	'*I know there's a Brian Clancy looking at getting PLEC funding to shift a transformers. It is an impact in the middle of a town where they want to have more kerb side seats. But to me if it's that much of an issue get the developer to do it. PLECS money should be reserved for undergrounding when you can. Drive around Mt Barker and look at the latest bit of ETSA pruning and you become very sad. The worst bit is coming in from Strathalbyn.*' - O - 6
96	Design\Infrastructure\Services\Undergrounding\ Versus	'*Getting things into specifications again, I keep nagging the engineers to make sure verges are wide enough because what's the point of having underground power then putting in small trees because your verges aren't big enough to have a big tree. You are losing your opportunity to have avenues of bigger trees.*' - O - 6
97	Design\Infrastructure\Services\Undergrounding\ Versus	'*Below ground. There's a real push for undergrounding of power lines. However I think perhaps the parts of the tree you don't see are the roots. It's not something that's actually acknowledged, that undergrounding power lines with existing mature trees may not necessarily be the answer I think. The bundling option may be more appropriate.*' - E - 5
98	Design\Infrastructure\Services\Undergrounding\ Vs	'*With verge widths becoming smaller and smaller, and new subdivisions going to underground services, it limits the opportunity we have. One of the few benefits of new subdivisions is that they usually put all services in a common trench. But if you follow the electricity Act we shouldn't be planting within 3m of an underground service. We would have no street trees if we abide by the regulators rules.*' - O - 4
99	Design\Infrastructure\Services\CST	'*Common service trenching.*' - O - 3
100	Design\Infrastructure\Services\CST	'*With verge widths becoming smaller and smaller, and new subdivisions going to underground services, it limits the opportunity we have. One of the few benefits of new subdivisions is that they usually put all services in a common trench. But if you follow the electricity Act we shouldn't be planting within 3m of an underground service. We would have no street trees if we abide by the regulators rules.*' - O - 4
101	Design\Infrastructure\Services\Planting over	'*Portrush Road, we have a central median that is 5m wide-good planting width. Below that we have a*

		stormwater pipe and then another. One is 750mm and the other 900mm. They are down about 700mm. The problem I have is we own one, the 900 comes from Port Adelaide Enfield and is designed to operate under pressure, so I've been reluctant to plant over it. Can it be done? ' - E - 7
102	Design\Infrastructure\Services\Root barriers	'*We have started doing a lot of root barriers to reduce impacts on infrastructure and get roots directed to deeper levels.*' - W - 3
103	Design\Infrastructure\Services\Root barriers	'*We may use root barriers, we may over-excavate areas. That also is given consideration.*' - W - 6
104	Design\Infrastructure\Services\Root barriers\Vs	'*With planning and design-this Council hasn't gone to any great extent to try and be creative as far as minimizing root activity with infrastructure, with root barrier and such. I know Arborgreen have got quite innovative ideas as far as managing tree root activity and allowing tree roots to survive within infrastructure. But there's obviously that cost involved in it that. In some cases we've used some root barrier, however it's debatable how effective they are. I see that sort of thing being used in major capital projects.* ' - W - 1
105	Design\Infrastructure\Services\Root barriers\Vs.	'*We are getting more and more requests for root barriers and things like that to stop tree roots going in there-which is not ideal either, cutting roots, but otherwise it ends up as a liability issue. No one has come up, to my knowledge, with a good outcome. Trees are smart aren't they. It depends on the quality of the root barrier-it will push the roots down, and I guess visually they won't be there. But as I said there's no silver bullet, so you have to do what you can with what you've got. We generally put the root boundary on the fence, property line.*' - W - 1
106	Design\Water\General	'*Water. In the future looking at maintenance, management implications of less water. In the future do tree planting well, rather than trying to get the maximum number of trees in the ground.* ' - E - 2
107	Design\Water\General	'*For us as an organisation it's all about water management.*' - O - 5
108	Design\Water\General	'*And that water will solve our problems in a way, to grow healthier trees.*' - O - 5
109	Design\Water\Regime	'*Water is part of the guy's program-we try to get everything watered at least once per month in the summer. If they can do it more ok, but at least its scheduled, every tree that gets planted to be done at least once a month. Our watering program starts basically from when the tree is planted, right through until the next lot of rain when it comes round in the following winter. Luckily we've got a bit of extra staff, so we can put that in the system this time around. Up to now we haven't had the staff to do it.*' - O - 1
110	Design\Water\Regime	'*Ideally its 2-3 years currently. They have done some trials putting in those water rings. Looking at different soil additives.*' - O - 3
111	Design\Water\Regime	'*With new trees they are watered every week for the first year, and fortnightly for the second year. And by that time they are generally on their own. They have to be, you can't continue to take care of trees. They have to be able to stand on their own.*' - W - 4
112	Design\Water\Regime	'*You can only do so much for them, they have to withstand high winds, and the pretty hostile*

		environment they live in. I guess Adelaide or SA is generally drier than most other parts of Australia.' - W - 4
113	Design\Water\Regime	'*We currently irrigate probably just enough for the tree in the first 3 years. We should probably double our frequency of watering if we were serious about it. But lack of resources dictates that at the moment. Once we get into the warmer weather we will up it.*' - E - 7
114	Design\Water\Additives	'*We have gone to using the water crystals-Terra Cottem.*' - E - 3
115	Design\Water\Additives	'*We have trialed some hydro absorbent polymers-we started last year with Alkosorb gel and Tera Cottem. One Council had undertaken their own trials with Terra Cottem-Mitcham. So for many years we weren't jumping on the bandwagon. A lot of people were skeptical about the use of it. So we are on board. Trialing it in different parts of the street with the same species so that when a WSP came up last year we had 6 streets, we were trialing different mulches and the hydro-absorbent polymers like Alkosorb and Terra Cottem. So we trialed different products, with groups of trees and not single trees. We're measuring height, caliper, photographing each tree.*' - W - 1
116	Design\Water\Additives	'*We use Terra cottem, we've been trialing that and it seems to be working.*' - O - 1
117	Design\Water\Additives	'*Soil additives. Terra cottem when we plant trees. Pick up rate and growth rate have improved. A large component is hydro-absorbent gels. Has a mix of different gels with different holding capacities and which release water at different suction pressures, making it available over a range of drying. We specify it and buy it by the palette load and use it to plant street trees. Takes longer to plant trees, need a bigger hole, backfill it and turn it all. When we water trees we can do it a little less frequently.*' - E - 4
118	Design\Water\Additives	'*Water management. There's a product we put in our tree holes as the tree is being planted. It improves water retention and aeration. Terra Cottem. The guys on the ground certainly think it's very worthwhile. And its proven in some of those areas recently planted that it has good effects.*' - E - 5
119	Design\Water\Additives	'*There's a couple of technical issues Use of Terra Cottem-water conserving at the root base.*' - W - 4
120	Design\Water\Additives	'*With water-using water conserving type materials.*' - W - 4
121	Design\Water\Additives\Versus	'*They claim we were the first Council to adopt it, to trial it. I don't believe it's the be all and end all, but it is like a little bit of an insurance policy. It's not the wonder product, the silver bullet.*' - E - 3
122	Design\Water\Additives\Versus	'*We have used varying types of additives in our watering regime but the jury is still out as to whether the benefits are cost effective. Our depot operations have chosen not to pursue it. I personally would have liked to have seen more comparisons/experimenting, but it has been decided, it was a waste of money. They don't believe in using Terra cottem either. Mike Oborn at Salisbury is using it, I ventured to see him some years ago. The Coordinator of Parks and Gardens doesn't believe in any of it. Treat them tough and see what survives and what doesn't.*' - W - 5
123	Design\Water\Greenwells	'*And the use of water wells around trees. Green*

plastic. Brian Measday developed them. He came to see us and I said it's a good product but a bit small. Alright for your home garden. When you come back with one three times as big we might consider it. And lo and behold he came back with the larger 3 panel system and we have taken them on board.' - E - 3

124 Design\Water\Greenwells — '*In addition we've been using the greenwell tree wells, to help hold some of the water.*' - O - 1

125 Design\Water\Mulch — '*And then we also use a lot of mulches-our own stuff that we chip up.*' - E - 3

126 Design\Water\Mulch — '*One of the challenge in the future is the SA Water restrictions. We're currently at enhanced level 3. I think they will always allow tree watering to occur. But not being able to water some of the reserves-those trees are used to a certain amount of water being applied around that base area and the root plate, it's just not getting that supplementary watering. So we are looking at mulching off extensive areas to protect certain trees.*
' - W - 6

127 Design\Water\Mulch\Gravel — '*We have also used gravel mulch along the verges as you can hand water with a hose without disturbing the mulch and it doesn't require replacement. Watering with a hose tends to blow organic mulch away and organic mulch also soaks up the water. The gravel mulch doesn't soak water up, its stable and heavy, you can put the hose on there and it doesn't wash away. I'm pleased to say that we have had good feedback on using the gravel mulch from our Maintenance Teams after some initial resistance.*' - O - 2

128 Design\Water\Recycled — '*Some of the new subdivisions, hopefully some of the recycled water, hopefully we can tap into some of that. So there's a couple of designs we are involved with. We have Bolivar, which doesn't come out this far. We put our name down for water for a few sporting complexes with ovals, we were hoping to use a bit of a mix. But they won't come out this far. So we are using e mains water which is quite expensive. The bore water we have tested out her is quite salty, but we may be able to use it in a mix, some homework to do there.*

' - O - 1

129 Design\Water\Recycled — '*That is a key thing to water management, because we get asked all the time, when we go out to consultation, how can Council afford to plant trees in the environment we're in. We follow the line, Council has access to a recycled water supply, its renowned for it across the globe, we are making use of that resource which is being reclaimed from what would otherwise go out to sea and to waste. Stormwater recycling and aquifer storage and recovery systems is the means by which we collect the stormwater.*' - O - 4

130 Design\Water\Recycled — '*The great thing is we have plenty of recycled water with which to water new trees. In terms of delivering it to trees, that's still to be fully resolved in how it is delivered.*' - O - 4

131 Design\Water\Recycled — '*We're looking at the possibility of actually using bore water to irrigate. I'm not sure that's all that wise. Time will tell.*' - E - 7

132 Design\Water\Recycled — '*Hydrasmart-they run a drip current around the pipe that delivers the water, and that changes the*

molecular structure of the water. Its old technology that's been around for a long time. But there is enough information out there to suggest it does work- and we are going to put that into one of our bores pretty soon. And they now supply a small unit to put on the back of your water truck that will do the same to your bore water from your water truck. So we are going to see just how the Perth exercise works. But if we can get a better quality out of the bore water, and naturally bore water at the moment is dropping in quality due to the drought. Some of our bore water is reasonably good, but salinity is the problem. But I'm sure we'll end up in a situation where we will irrigate one week with bore water, the next week with mains water, just to flush out. Adelaide Oval they used it when they were pumping from the Torrens. At Burra they were using it to treat bore water for irrigation. And a lot of vineyards, a few school ovals have been done. Sand I've heard of so many say it's good that I'm confident.' - E - 7

133 Design\Water\Harvesting

'*Currently looking at a concept for stormwater harvesting with a 1m deep geotextile lined infiltration pit located between street trees in the verge. This will be fed by a pipe from a kerb inlet, which returns to the kerb for overflow when the pit has filled with stormwater. Then overflow then goes to the next tree in line. Don't need to collect all the runoff. A simple solution, not over engineered. Tree roots will find the water-it does not have to be delivered to the base of the tree. The tree has the capacity to draw it out of the soil. There are a lot of grass verges in Burnside- and residents are watering less. So with stormwater harvesting there will be less need for street tree to find water in private front yards. There will also be less infrastructure conflicts as roots will stay in the verge. The aim is to push water to the footpath and away from the kerb. The first section of the inlet pipe may therefore be sealed.*' - E - 2

134 Design\Water\Harvesting

'*Water management in the one's in Main Street is ag. pipe, we've got to manually water, but it's got two systems. It's got an outer ring and an inner ring. So hopefully it gets enough water to keep the trees going. One outside the root director, and one inside the root director. We got the soil from Jeffries, it's like an aerated soil, with polystyrene in it. We picked it up from Wayville Showgrounds, they planted trees and paved around the trees in Wayville Showgrounds, we made enquiries. That's how we got where we are now, and all the stuff they used down there we used here.*' - O - 1

135 Design\Water\Harvesting

'*We are experimenting with a system on Seaford Road to address that the issue of introducing water to where its most needed, at the roots. It's really simple, just a ring of ag. pipe or drain coil installed when the tree is planted just below the level of the root ball and a bit out from it, with a couple of risers coming up with caps on them. Then you can just charge the water into there and it sits in a horizontal plane to be absorbed into the subsoil at the root level. It's not like the loop under the root ball where the water just fills up at the base; the horizontal ring allows the water to spread out in the root zone. It will be interesting to see how it goes. It's not rocket science and there are commercially available versions about but we wanted*

		to see how simple it could be. Time will tell how successful it is.' - O - 2
136	Design\Water\Harvesting	'*New methods?*' - O - 2
137	Design\Water\Harvesting	'*We made a decision not to install an irrigation system as it was going to cost around $50K and we figured you could get a lot of hand watering for that amount of money.* ' - O - 2
138	Design\Water\Harvesting	'*In terms of streetscape design, we are currently doing some work on Walkerville Terrace-or planning it. And we are looking at some options to try and be a bit more innovative in the way we water the tree, and house the tree. But I also want to carry that through to some of the local roads we are doing. Passive irrigation, trying to take water from the road itself.*' - E - 7
139	Design\Water\Harvesting	'*One alternative is to have a catchment area and you have a pumping system.* ' - E - 7
140	Design\Water\Parks	'*The other thing we are doing as part of this strategy is a Park Adaptation Program. We look at our parks and reserves. Because the water restrictions have had a huge impact on our turf in parks and reserves, and as such it had a huge impact on the use of parks and reserves. Looking at the opportunities where we can to create biodiversity, re-landscape our parks so there's less reliance on turf and more on sustainable landscape. Which will also give us the opportunity to plant trees that will become significant.*' - E - 6
141	Design\Water\Parks	'*Andrew Crompton at Burnside was very much ahead of his time-he came in at the right time-didn't have a lot of resident conflict. Beaumont Common. The fact they have more open space than us helps.*' - E - 6
142	Design\Water\Parks	'*We tried to a similar thing here at Haywood Park. Only in 2 places in the Adelaide Plains with Eucalyptus microcarpa found in its remnant form - Burnside Common and Haywood Park. At Beaumont Common he created mulched areas ,he's hoping the microcarpas will regenerate. We created mulched beds at Heywood park but they wouldn't let us plant biodiversity in the mulched beds. Hasn't stopped us collecting seed from the microcarpa, growing them on and planting them back in the park. There's also a little fenced areas around 3 remnant microcarpa..*' - E - 6
143	Design\Water\Parks	'*What we are finding is that in parks we are shifting the focus-for years our irrigation systems in parks were directed towards turf maintenance. Water restrictions have basically forced us to turn off our watering systems. Now we are redirecting that water to arboriculture. You can get away with in-line drip feeds, in-line systems. Shifting it from turf to trees. We've got mainly kikuyu turf-only needs one rain and what you thought was dead is green again. I think our parks of the future are going to be different to our parks of today. When you consider that my children 10 years ago, when I took them to the park in the middle of summer, they could sit on green grass kick a ball on green open space. The question is can tomorrows child be able to do that? I know they can't in Unley because most of our parks, the water restrictions mean we are back to one night a week or not at all. So then what use is the park. We will be removing turf and extending that to become garden areas. Some would say that's a good thing, some that its limiting access to open space to kick a ball*

		' - E - 6
144	Design\WSUD\Extent	'*And when we rebuild roads, somehow trying to get that water table water, instead of pushing it down to the sump and into the stormwater system, actually diverting it back into the nature strip.*' - E - 3
145	Design\WSUD\Extent	'*There is a system happening at Lochiel Park, but that's a State government project where they are putting swales and stuff in there.*' - E - 3
146	Design\WSUD\Extent\Projects	'*We just did one several months ago that was a quite sizeable tree, a circumference of about 7 metres. It was right in the road, and over the years we built the road right around it. And the guy said we have to rebuild the road, how are we going to do it? The tree has to stay, it's like a local icon. We explored the avenue of WSUD. We ripped up all the bitumen that was around it, air knifed after that to find the root zone, and put in some good sized rock and some geotextile. And we are now running the stormwater and the street water straight into this area. We've also planted a reed bed over the top of it. So we are hoping it won't break up the road anymore, it is also reducing the stormwater runoff, and hopefully keeping the tree in good condition.* *The groundwater has dropped, which is not getting the rainfall, so it's a concern that the subsoil is drying out more than it ever has and a lot of these trees won't cope. So we are looking at that as possibly being a savior. At the same time showing that roads and concrete and trees can mix together. Fairleas Road, near Stradbroke primary school. The reeds have probably tripled in size, and they were only planted about 2 months ago.* ' - E - 3
147	Design\WSUD\Extent\Projects	'*WSUD-I haven't been involved a lot but we are actually going through one now. And were just in the consultation process. This basically started in a large subdivision, a fragmented subdivision in the Bowden/ Brompton area-and there's quite a bit of development. With these new subdivisions new tree planting occurs, however the rest of the street looks pretty ordinary as far as the streetscape goes. So the residents and myself had a discussion, some 18 months ago, and put it to our engineers-there's a lot of footpath damage from some of the existing trees, some with no trees at all, the roads are in poor condition. However because they didn't meet their road reconstruction criteria in the near future, we'll have to put up a project bid to Council to get it up and running. I was at the first part of the consultation with the residents and so the consulting planners, Jensen's, have provided a few options for 3 streets-with modified raingardens, trying to encourage some better streetscapes. Green Street, West Street. We've also had a look at Unley Council's initiatives at Windsor Street, and also Duthy Street which is not as grand as Windsor Street. It was open concrete drain and the engineering department had to reconstruct the drain and obviously the streetscape came with it*' - W - 1
148	Design\WSUD\Extent\Projects	'*We've got a couple of WSUD projects.*' - E - 6
149	Design\WSUD\Extent\Projects	'*We've done some work in George/ Duthy Street with WSUD.*' - E - 6
150	Design\WSUD\Extent\Projects	'*Down at Everard Park, one at Hallman Avenue-with a bit of luck that will provide us with some more*

	space for the trees to grow in.' - E - 6
151 Design\WSUD\Extent\Projects	'*WSUD. We are trying with this particular project. And that will give us a lead into some of the other ones we are looking at doing*.' - E - 7
152 Design\WSUD\Extent\Want to	'*I've been speaking to some of the government agencies and there could be money to do a lot of this WSUD if you've got the right projects.* ' - E - 3
153 Design\WSUD\Extent\Want to	'*WSUD. I was involved in some of the works in Brisbane-suburban centre improvements, trying to push it a bit. Do some trials. Getting stormwater off roads and even off private roofs before it hits the kerb and water table and introduce those into tree pits. Trying to do some of that here as well. The great thing in the plains environment you can do that quite easily because of the levels*.' - W - 3
154 Design\WSUD\Extent\Want to	'*Want to do for surface soil recharge what Colin Pitman has done for aquifer recharge at Salisbury.* ' - E - 4
155 Design\WSUD\Extent\Want to	'*Stop talking about it, let's do it. Will be kudos for the council that does it*.' - E - 4
156 Design\WSUD\Extent\Want to	'*If we had our way we would use tree trenches, kerbing, the latest and greatest ways of stormwater harvesting*' - O - 6
157 Design\WSUD\Extent\Want to	'*The stormwater engineer and I keep battling for opportunities to incorporate WSUD into streetscapes. We are both aware of the technologies, and we keep trying to look for opportunities to push it*.' - O - 2
158 Design\WSUD\Extent\Want to	'*Water management is something we've discussed as a design group, with civil, for the future and is something we want to pick up and move forward with. It's something we have identified with a number of developers we have close contact with. This is the direction forward that needs to be taken. Either retention on site, or some detention on site, for the benefit of an open space or green environment*.' - O - 4
159 Design\WSUD\Extent\Versus	'*Hopefully we will get in a situation where we can do some of that. Because we are already established and don't really have any land we can subdivide. A lot of land that gets subdivided now is private people, they just want the straight road in there, kerb and water table. It would be interesting to adopt some of these things in new areas, but its extra money to them, they don't feel comfortable to trying it. There's probably that liability thing as well. And they just go the traditional way because they know it works*.' - E - 3
160 Design\WSUD\Extent\Versus	'*WSUD in the street environment is being discussed, is it being initiated? Well we are in the early stages. We don't have any examples at this point in time. I think that Cheltneham Racecourse is one that will come as a major project for Council as far as WSUD comes into it*.' - W - 1
161 Design\WSUD\Extent\Versus	'*Charles Sturt is pretty flat, and there is fine line to keeping that water moving. With time some of that resolution may come into different designs-why do we need straight concrete lines and water fall down to the end of the street to a SEP. So that's where the interaction between designers, landscape designers, also architects having an input into modifying stormwater runoff*.' - W - 1
162 Design\WSUD\Extent\Versus	'*WSUD-we don't do much. You could argue putting the trees in the actual road corridor, you no longer have a kerb so there's the opportunity for water.*' - O -

		3
163	Design\WSUD\Extent\Versus	'*In terms of a true integrated stormwater street tree planting design, no.*' - O - 3
164	Design\WSUD\Extent\Developers	'*They are the sort of things we can hopefully over time to introduce into specifications for new development, and developers pay for it. Once you get it in and can demonstrate the benefits of it, it sometimes gives you an argument for the benefits of retrofitting it in different spots when anything is being upgraded.*' - O - 6
165	Design\WSUD\Extent\Developers	'*Water management is something we've discussed as a design group, with civil, for the future and is something we want to pick up and move forward with. It's something we have identified with a number of developers we have close contact with. This is the direction forward that needs to be taken. Either retention on site, or some detention on site, for the benefit of an open space or green environment.*' - O - 4
166	Design\WSUD\Issues	'*WSUD keep looking at them, with stormwater engineer, but it is difficult with established roads. It's a big cost, and the last thing engineers want is to undermine their wonderful bits of bitumen.*' - W - 5
167	Design\WSUD\Issues	'*More inventive products and schemes which allow water to enter tree bowls and benefit the tree is essential. Issues arise with the road bases which have to be constructed not to withstand moisture. So specifically designed areas need to take this into account. Another cost factor, but if that initial cost was implemented early/ first off it would be more beneficial long term.* ' - W - 5
168	Design\WSUD\Issues\Engineering	'*The concerns from our engineering department are the potential for water seeping into the sub base and destabilizing the bases is a concern for them.* ' - W - 1
169	Design\WSUD\Issues\Engineering	'*There are concerns putting water into soils in concentrated areas-but may reduce current problems with soil movement we've come to accept. Putting summer showers into dry soil we may take out the peaks in the variation in soil swell volumes. Keeping it moist may reduce impacts rather than increasing. It's the soil drying out totally that shrinks it and causes problems with cracking. .*' - E - 4
170	Design\WSUD\Issues\Engineering	' *The whole WSUD principles, it will be interesting to see how it gets picked up, because there is a cost for that implementation up front, does that get passed on to the purchaser of the land, and is there a marketability or profit that subdividers or developers can get out of their process by including it.* ' - O - 4
171	Design\WSUD\Issues\Cost	'*It would be interesting to adopt some of these things in new areas, but its extra money to them, they don't feel comfortable to trying it. There's probably that liability thing as well. And they just go the traditional way because they know it works.* ' - E - 3
172	Design\WSUD\Issues\Cost	'*Its an expense and when you are talking about the Playford North project there's a whole heap of other dynamics around that fundamentally to do with housing affordability. If you are going to put in big bucks on engineering you are going to come up against those sorts of issues.*' - O - 3

173	Design\WSUD\Issues\Cost	' *The whole WSUD principles, it will be interesting to see how it gets picked up, because there is a cost for that implementation up front, does that get passed on to the purchaser of the land, and is there a marketability or profit that subdividers or developers can get out of their process by including it.* ' - O - 4
174	Design\WSUD\Large scale	'*In terms of WSUD another school of thought, the general engineering solution is let's gather all this water up and get it out of here. But when we do that we do it in a concentrated, centralized way where all that water's captured, shoot it off into typical engineering solution, but it ends up in a wetland system, then that becomes the WSUD rather than doing it site specific wherever the tree is. We are collecting it, purifying it, injecting it into the aquifer and looking at a trading scheme of points for sucking it out somewhere else that its required in more of an integrated approach. Can go beyond Council boundaries, we are part of the waterproofing the north project ,that's Playford, Salisbury, Tea Tree Gully. It's a little like the rainwater tank debate-everyone is to have a tank-but hang on, we don't want everyone to have a rainwater tank because we want that water, and will deal with it. Plus there's a good business case for that with the price of water.*' - O - 3
175	Design\WSUD\Perm surfaces	'*We've been trialing flexible pavements in a couple of areas with a significant tree that we want to retain. And they have ongoing problem with lifting the footpath.* *We installed a couple of those treatments in an attempt to,* *Stop the public liability issue of trip hazards.* *Give an area with some permeability to get a bit of water onto the trees*' - W - 2
176	Design\WSUD\Perm surfaces	'*rising temperatures are a big concern. 3-4 degrees temperature rise on pavement is going to kill root growth in surface layers. Going to need to design better insulated surfaces. Permeable paving with increased aggregate depth below it to get roots to grow deeper, will insulate it more, and have access to more moisture.* ' - E - 4
177	Design\WSUD\Perm surfaces	'*If we average our footpaths at 1.2m wide-it may be wider- we have 60ha of footpath, which equals 600,000 sq m. So 1.5 mm of rain would give us a megalitre (or 0.9 of) pretty extreme, just for footpaths. Average rainfall is 500mm. So 300ML falls on our footpaths in an average year.*' - E - 4
178	Design\WSUD\Perm surfaces	'*Our roads. An average road width is 8 m. So we get an average of 2 GL of rain falling on our roads each year. If we had pervious paving?* ' - E - 4
179	Design\WSUD\Perm surfaces	'*Standard pervious pavers are very thick, 80mm for trucks. Need footpath depth pervious pavers 30-40mm, most Council's use 60mm. Interlocking pavers are best as they don't spread, don't need edge restraint.*' - E - 4
180	Design\WSUD\Perm surfaces	'*Council sees that as an issue. That's why we're trialing things like permeable paving, we've got a site over at Oxford Terrace, where we're working with TREENET.*' - E - 6
181	Design\WSUD\Perm surfaces	'*We have also introduced specific water permeable verge materials to absorb water/moisture rather than a dolomite or quarry rubble. The aggregate is*

		enhanced with a poly resin allowing water to enter the ground immediately around the tree. We have started removing dolomite verges and replacing with this type of material, and we are finding it very, very good. Trying to increase the water going down to our street trees and hopefully reducing infrastructure damage. Small things. Everything helps. ' - W - 5
182	Design\WSUD\Perm surfaces	'*The use of porous paving and root directors, on some of our main thoroughfares, has proven to work favorably.*' - W - 5
183	Design\WSUD\Harvesting	'*Doncaster Avenue ultimately the way to go provided we can do it without exposing Council to any liability from effects of soil movement or pollution. I believe we can but need to check that. One tree without much growth doesn't have a soakage trench. May just be the tree? It will tap into those trenches eventually. In 3 years it will make no difference. Ultimately a great way to water our street trees. Trees are offset by a couple of metres from the trench.* ' - E - 4
184	Design\WSUD\Harvesting	'*With an average verge of 3 m width, with 2 m footpath, have 2 metres of water running off a paved surface. Short showers sit at the edge of the footpath so that's where roots run and crack up the footpath. With permeable paving with water down deep roots would go deep without lifting the footpath. Thinking about recharge value a cu m of clay can hold an average of 400 litres. Permeable paving would stop that water running off so it can infiltrate. With average rainfall half a metre a year that would saturate clay down to 1.2-3 m. which is where tree roots are. If we put a tree every 15m over 3m wide verge and get all the rain that falls onto that verge into the soil. Not allow for drip through and canopy interception, looking at young trees, 15 x 3, 45 sq m, half a metre rainfall we're looking at 22.5 KL falling around that tree. 400 litres to the cu m, looking at just over 50 cu m of saturated soil at field capacity. That tree will tap into in spring, recharge in winter, get some summer showers to top it up. If we use WSUD and keep all the water that falls there, you might get 50 mm in summer, 50 mm over 4 square metres is another 2 KL available to the tree enough to saturate another 5 cu m, saturated with 2 KL. Won't need to water our trees if we get the rainfall to stay there, plus get some off road. Not too much to cause problems. Plenty of capacity in the soil to store enough water for those trees. If we store it where we want the roots to grow, that's where they will grow.* ' - E - 4
185	Design\WSUD\Harvesting	'*The drawback is once you get a large canopy you're not getting much rainfall at all. We will need to intercept off the road. That's when we will really see the benefits in pollution reduction, peak flow reduction, flooding reduction. We start to get all that. Needs to be full on.*' - E - 4
186	Design\WSUD\Harvesting	'*Want to do for surface soil recharge what Colin Pitman has done for aquifer recharge at Salisbury.*' - E - 4
187	Design\WSUD\Harvesting	'*Will monitor Doncaster and Dorset for impacts on the soil*' - E - 4
188	Design\WSUD\Harvesting	'*With Walkerville Terrace we are looking at capturing stormwater from the roadway. We have to do roadworks for 50% of the road and we can re-jig things and catch water where we can.*' - E - 7

189	Design\Species selection\General	'*The species of trees that we plant*' - E - 1
190	Design\Species selection\General	'*At the moment its best practice planting, and species selection, and also quality of stock, is about all we can do at the moment.*' - O - 6
191	Design\Species selection\General	'*With regards to the latest trend in tree planting-we're an active member of TREENET. We work extensively with the information available from that group-taking into consideration the species selection, the sustainability, longevity, the growth patterns of trees. We take all that into consideration. And the criteria for all of that-we also make sure that people who do the work within our Council area, namely developers, that they adhere to that.*' - W - 6
192	Design\Species selection\General	'*Tree species, that's where we have tried to step up to the game.*' - O - 4
193	Design\Species selection\General	'*And probably tree species selection as well. I think those two can solve a lot of our problems.*' - O - 5
194	Design\Species selection\General	'*Tree species selection.*' - E - 7
195	Design\Species selection\General\Lists	'*Tree species is part of that review. At the moment they've got a tree planting guide they ne to stick to. It's quite a reasonable selection that's been developed in collaboration with Adelaide Botanic Gardens-Tony Whitehill.*' - W - 2
196	Design\Species selection\General\Lists	'*In collaboration with the Maintenance Team I am currently working on the development of tree planting guidelines including suggested species and preferred planting practices. A landscape designer has been employed by Council for a number of years and there is a wealth of experience in Council about what does or doesn't survive under the local conditions*' - O - 2
197	Design\Species selection\General\Lists	'*We do have a preferred planting list.*' - W - 6
198	Design\Species selection\General\Lists\No	'*In terms of tree species selection, we are trying to get a more holistic framework. It was certainly one of the issues when I first came on board, that we didn't have any real strategy for street tree planting and replacement when trees died, as to what species would go in. I think that's part of the strategy that needs to be developed, is suitable species choice in a street.*' - E - 5
199	Design\Species selection\General\Lists\No	'*Its one of those issues that reflected back on past Council practices. The Council area was divided up into almost all old Council boundaries, with the Parks and Gardens teams. It didn't really reflect the previous Council boundary planting selections, except in the instance of St Peters which had a very strong tree management and protection flavour. But when I asked the guys on the ground a couple of years ago how they did choose their trees it actually came down to a personal preference. Pyrus, golden elm, jacarandas, so we've quickly come up with a replacement plan to get some diversity across the field.*' - E - 5
200	Design\Species selection\General\Diversity	'*Part of this review is to look at more variety. They have used a lot of Callistemons in the city. Part of the strategy is trying to start having avenue plantings-remove the stock, put new trees in But we've got to make sure they meet the challenge of climate change: drought tolerant, used to floods, major flood events, major storm events. That's the prediction, and with reduced rainfall.*' - W - 2
201	Design\Species selection\General\Diversity	'*We've only got about 20 odd species we use.*' - E - 7
202	Design\Species selection\General\Range	'*And one of the things that's important, with some of the successful plantings in those areas, is the new trees have come on-line through the respective*

		nurseries. Some of the cultivars, the Corymbia ficifolia summer beauty, some of them are really successful. ' - W - 6
203	Design\Species selection\Criteria\Size\Smaller	'*What I like to do is try and be open to new ideas, if someone comes up with a specific species for an area, like main roads. Everyone thinks with main roads you've got to have a Plane tree or a citriodora. I think you can go with something smaller, that's going to have less maintenance, less impact on adjacent businesses and properties, but still provide that look of greenery.* ' - W - 6
204	Design\Species selection\Criteria\Size\Smaller	'*If you turn the clock back, 20-25 years ago, a lot of people went nuts planting Plane trees, then they thought these are getting big, might cause problems , they went away from Planes and planted bottle brush trees under the wires. And then you had that stint when people were trying prunus.*' - W - 6
205	Design\Species selection\Criteria\Size\Smaller	'*We are tending to look very carefully at Crepe Myrtles, Photinias (being almost shrubs basically we can prune them). Crepe Myrtles we have started to move into in a lot of the smaller streets.*' - E - 7
206	Design\Species selection\Criteria\Size\Smaller	'*We've gone with the Pyrus chanticleer-which is a bit upright and seems to fit well into the narrower streets.*' - E - 7
207	Design\Species selection\Criteria\Size\Smaller	'*Whereas the Pyrus, I reckon they are going to be a bit bigger. I know they are, there are a couple at The Waite Institute, that have to be 60-70 years old. Our neighbours to the north, Prospect, they have a little street with a Pyrus planted in only 200mm of verge. And we've done some silly things too, so we're not immune.*' - E - 7
208	Design\Species selection\Criteria\Size\Match tree site	'*And again just choosing the right species for the right location.*' - E - 1
209	Design\Species selection\Criteria\Size\Match tree site	'*Salisbury, when they started they went out really heavily putting in the large trees. These trees, your ironbarks and all that, they're just too big for where they put them. And unfortunately now after 20-30 years they have had to start ripping them out, which is a shame. They are quite visibly going through and just clear felling massive amounts of trees.*' - E - 3
210	Design\Species selection\Criteria\Size\Match tree site	'*Basically plant the right tree in the right location. Where we have a smaller available space, consider the knowledge of tree species-say in some instances where we do have narrow verges, smaller trees.* ' - W - 1
211	Design\Species selection\Criteria\Size\Match tree site	'*What we then have to be careful of is the selection of the tree for that available room.* ' - W - 6
212	Design\Species selection\Criteria\Size\Match tree site	'*What we do is we pick species, taking into consideration the available planting room.*' - W - 6
213	Design\Species selection\Criteria\Damage	'*Tree species selection-in the sense-does it have vigorous, spreading root system, which will cause problems down the trail with infrastructure.* ' - E - 2
214	Design\Species selection\Criteria\Damage\ETSA	'*We won't replant with spathulatas, they are an inappropriate species an absolute pain due to branch failures. We had a massive program going back 10-15 years ago, where we worked in conjunction with ETSA. Due to the fact that the spathulatas were causing a lot of problems with their (ETSA) infrastructure. We had a program where we worked together to remove them to remove spathulatas and to replant with a more suitable species.*

		' - W - 6
215	Design\Species selection\Criteria\Damage\ETSA	'*Where we're going to go back to redo a street we may replant with a new species, Part of replanting process is to do an assessment of under-wires, free of wires, to ensure we are not going to have trees long term that conflict with the electrical wires.* ' - W - 6
216	Design\Species selection\Criteria\Damage\ETSA	'*If it's a street that we are retrofitting, if the existing trees are suitable to be retained, we'll retrofit with the existing species, because we are allowed to under the ETSA line clearance Act.*' - W - 6
217	Design\Species selection\Criteria\Climate	'*Tree species selection. We are looking at some of the dryer species. We have trialed the Gidjera (Wilga) just for the last couple of years. It seems to be kicking on. But it's such a finicky to start getting established. And we still have the mindset that it needs water, and kindness. In actual fact the ones that are not in grassed verges but in actual rubble or just dirt are doing a hell of a lot better. They seem to be ones that can handle neglect. That's one tree we have been trialing and will probably do some more next year. Some of the smaller Eucalypts, the grafted Eucalypts, summer red. Evaluate.*' - E - 3
218	Design\Species selection\Criteria\Climate	'*trialing those because they are of a short size, and quite attractive. We have people who are quite accepting of them. Then we always have people who say, it's a gum tree, it will be huge-but we try and tell them it's not. As planting season comes closer we letterbox our streets-the resident gets a postcard outlining species, its flowering time, any attributes. And on the front we try to get a picture of a tree around the 10 year old mark. So people can see this tree is going to be say 6m by 4m in 10 years. We try and educate the public, make them feel comfortable.* ' - E - 3
219	Design\Species selection\Criteria\Climate	'*We are also planting the Tuckeroo. They seem to be quite resilient actually. They don't mind the bore water either. Evergreen, so leaf litter is not such an issue. But still younger days on them. I've yet to see them 20 plus years old. The first ones I ever saw were down in front of Botanic Park, at this stage they are probably only 15 years old.*' - E - 3
220	Design\Species selection\Criteria\Climate	'*But we've got to make sure they meet the challenge of climate change: drought tolerant, used to floods, major flood events, major storm events. That's the prediction, and with reduced rainfall.* ' - W - 2
221	Design\Species selection\Criteria\Climate	'*I guess with the plains in Adelaide there's a fairly limited selection. A bit hotter, a bit dryer. There's still quite a lot of interesting plantings the SAHT used. In fact one of our theme trees is the Brachychiton, the bottle tree, and there are old SAHT plantings in Munno Para, as well as some fantastic Fraxinus raywoodii in some of the older parts of Elizabeth South.*' - O - 3
222	Design\Species selection\Criteria\Climate	'*There has been that push late in the last decade, and early in this one, to see an increase in exotics across the city, which haven't proven themselves. We've seen a number of those fail or suffer poorly with Salisbury's climate. Because the conditions they are in are not suitable. We've tended to stick largely to a native palette, which is indicative of the areas native vegetation, or is very close to. Which can*

		survive in the varied conditions the city has.' - O - 4
223	Design\Species selection\Criteria\Climate	'*Things like your Tuckeroos, I think Burnside's planting a lot of Tuckeroos, which are a tropical, and the supplier will tell you they can grow 2m in one year, when they're young. They're becoming popular and they survived the 45 degree sun as well the other day.*' - O - 5
224	Design\Species selection\Criteria\Climate	'*Portrush Road in Magill-people think the native grasses are weeds!* *I don't have a problem with roses, they are very low water consumption. We've planted some that are not very good, but the ones out here get about 20 minutes a fortnight, probably more than it needs.* ' - E - 7
225	Design\Species selection\Criteria\Coastal	'*We've got the NZ Christmas tree. A lot of plantings along the coastline, which is a very hard environment. A common thing for seaside Council's-a very challenging environment for street trees along the foreshore area. You can see as you come back from the coast in the more traditional eastern suburbs Council, they don't have those issues.*' - W - 2
226	Design\Species selection\Criteria\Coastal	'*Norfolk Island Pines are an iconic image of sea side Councils. There's very much a political and a social push to keep that plant. Which impacts when you've got powerlines, infill, with a big tree. Some of them are stressing and dying. But we are planting more and more. Increasing our stock, not reducing.*' - W - 2
227	Design\Species selection\Criteria\Coastal	'*We're using the NZ Christmas Tree, they are growing stock to try and make them into a street tree.*' - W - 2
228	Design\Species selection\Criteria\Native	'*trialing those because they are of a short size, and quite attractive. We have people who are quite accepting of them. Then we always have people who say, it's a gum tree, it will be huge-but we try and tell them it's not. As planting season comes closer we letterbox our streets-the resident gets a postcard outlining species, its flowering time, any attributes. And on the front we try to get a picture of a tree around the 10 year old mark. So people can see this tree is going to be say 6m by 4m in 10 years. We try and educate the public, make them feel comfortable.* ' - E - 3
229	Design\Species selection\Criteria\Native	'*And admittedly a lot of native species, there's quite a lot of variability in form, and a lot of them are pretty massive trees. I guess that just reflects the short time that we've been messing around with these things. The Corymbia maculata is probably an exceptional one, where they're really getting a consistent form, and you can be assured you will have that uniformity. That's probably one of the fundamentals, in terms of amenity, in terms of visual impact. You are probably aiming for uniformity in the creation of that streetscape.*' - O - 3
230	Design\Species selection\Criteria\Native	'*We don't encourage the use of Plane trees-maybe it's a point of difference for us. This is not a Council position, but my personal opinion is that deciduous plantings certainly have a role in terms of solar access, depending on the orientation of the street. And for me in terms of the maintenance it's just a different regime. All trees are inherently messy, it just happens that they make a big mess in a concentrated period. So if you can manage that leaf litter load. You often hear that issue of leaf litter getting into waterways-if that can be managed then*

		there is a good argument for deciduous plantings.' - O - 3
231	Design\Species selection\Criteria\Native	'*The city has varied landscapes from coastal, foothills and all that is in between. There are certain areas where we can see larger installation of ornamentals, if that is what the council chooses. But we have to look at proximity to the natural or recreational resources the city has. We've got one boundary that runs through Cobbler Creek Recreation Park, so we want to build on that environment and character by continuing through a native palette. We've also got Dry Creek and Little Para, riparian environments with a high value native base, and we try to tie into that whenever we can.* ' - O - 4
232	Design\Species selection\Criteria\Native	'*There has been that push late in the last decade, and early in this one, to see an increase in exotics across the city, which haven't proven themselves. We've seen a number of those fail or suffer poorly with Salisbury's climate. Because the conditions they are in are not suitable. We've tended to stick largely to a native palette, which is indicative of the areas native vegetation, or is very close to. Which can survive in the varied conditions the city has.*' - O - 4
233	Design\Species selection\Criteria\Native	'*Bob Sutch planting sends me a letter about Australian natives in streets. I think about 20% of our street trees are natives. We are planting about 2000 native trees and shrubs per year, compared to about 100 to 150 exotics. We have about 3,600 street trees and we work on 3% turnover each year if we can.*' - E - 7
234	Design\Species selection\Criteria\Longevity	'*Golden Grove is simply poor tree selection. I think trees were selected on a theme, rather than longevity. So its fine, the trees have got 20 years. They look good. But 20 years is not enough for a tree. I reckon you need a kind of design criteria for a street tree. And 20 years is still a good wicket, given all your car impacts and oil and all those sorts of things. But I think if you looked at their design lifespan, I think you'd go their design life was 10 years. And we should be aiming for like 40 years. You're going to build this subdivision, here's the top 10 things you have to do, and one is to get 40 years out of your street trees. Because when you add up all the cost of them. The bigger they are the more benefits they provide.*' - O - 5
235	Design\Species selection\Criteria\Preferred sp	'*But I think one of the most suitable trees I've seen, and it's very resilient, sustainable tree is the Pyrus chanticleer or capital. I reckon they are fantastic, so, so tough. And they are on a lean root stock, so they are not going to cause problems with infrastructure.* ' - W - 6
236	Design\Species selection\Criteria\Preferred sp	'*We were lucky that years ago someone had the foresight to plant Golden Rains-everyone's got their favorite tree but I quite like them Because they're a nice spreading tree. The leaf that does fall, falls pretty quickly. Easy to clean up-decomposes pretty quickly. Pretty hardy, they don't need a huge amount of water. Good shade. And survive a reasonable length of time, we're getting 50-60 years out of them. So they tend to like this spot for some reason.*' - E - 7
237	Design\Species selection\Strategies\Removals	'*It seems whatever's in the street tends to remain in the street in the long-term, unless of course there's a major reason for taking it out. If the residents get together and say we don't like any of these trees, get*

		rid of it.' - E - 7
238	Design\Species selection\Strategies\Removals	'*We have a policy that we don't take every tree out of the street, if we do we may take every second or third tree out. It might take us 10 years to change a whole street, because of the effect it has. Not that we've done that very often.*' - E - 7
239	Design\Species selection\Strategies\Retrofitting	'*if it's a street that we are retrofitting, if the existing trees are suitable to be retained, we'll retrofit with the existing species, because we are allowed to under the ETSA line clearance Act.*' - W - 6
240	Design\Species selection\Strategies\Retrofitting	'*Someone wants a Cupresus torulosa removed. We would never have planted them. When we go back and re-do that street its making sure that we plant with something a bit more suitable.*' - W - 6
241	Design\Species selection\Strategies\Awareness	'*We always keep an eye out, and keep an eye out on our fellow brothers next door. If we are driving around the area or catch up at TREENET, what are you guy's planting, what's going on in your area. Marcus Hanthan and Simon Gibbons at TTG.*' - E - 3
242	Design\Species selection\Strategies\Awareness	'*We are spending a bit more time now trying to research different plants and tree species. Talking to other Councils, talking to some of the wholesalers. Trying to look at what is working elsewhere. We seem to be on the outer edge, and look over the fence all the time, seeing what other people are doing. In the Main Street we planted Japanese Pagoda trees. The Councilors selected those trees. We are actually putting in pots with seedless olives in them, which weren't what we wanted either. That's a bit of controversy*' - O - 1
243	Planting and estab\General	'*The species of trees that we plant. And the management then thereof –like pruning, maintenance.* ' - E - 1
244	Planting and estab\General	'*And also what's changed a lot, in the way we do things with street tree planting, is the methodology of planting. And it starts with having suitably qualified staff. Getting good stock, and appropriate stock and probably doing a better level of forward planning. And then having the follow up maintenance to ensure the trees are maintained.*' - W - 6
245	Planting and estab\General	'*And we try to make sure when we finish the work off we prepare the area, we put a tree well in, we mulch off, and we double stake trees, double tie them.*' - W - 6
246	Planting and estab\Stock\Size	'*We generally try to plant our trees at 1.5m. People still can't perceive what they are going to look like. So they get these and think, that's a nice tree and hopefully in return, when we get hot weather and our guys are out on the water truck, they will take the onus on, and if I give that tree a bit of water I will have nice shade for the visitors in a car, or makes my house look better. That's been good and we have a phone number on the back, so people can ring up with queries. Or if they think we've used photoshop on that tree, where is there actually one in the district.*' - E - 3
247	Planting and estab\Stock\Size	'*Most of our stock out of nursery is, I think, in 25 litre bags. And we don't go bigger than that because of the manual handling issues. But generally we can get a nice girthy 2m specimen for the streetscape in a 25 litre tub.*

		' - W - 6
248	Planting and estab\Stock\Size	'*The former Council was using tube stock-and the failure rate was huge. We changed the culture from tube stock to planting with advanced specimens.*' - W - 6
249	Planting and estab\Stock\Size	'*We've got the White Cedar replacement issues. We've got 4m trees, quite big, very good stock. They have got the advantage, if you are removing the tree you are putting in a big sized tree. People get an instant effect. I think now we're of that era, they like to see something happen, that perhaps years ago wouldn't have happened.*' - W - 4
250	Planting and estab\Stock\Size	'*So they feel they are getting a better service, a better tree. In some ways I can't argue whether those trees will grow at the rate of a 1 m tree. But it's a politically acceptable outcome, to use the bigger trees.*' - W - 4
251	Planting and estab\Stock\Quality	'*Quality of the planting stock. Shape, form, good root structure.*' - E - 2
252	Planting and estab\Stock\Quality	'*All our stock is contract grown, we don't have our own nursery. We buy a lot of our trees from Adelaide Advanced at Cherry Gardens-all grown in rocket pots*' - E - 3
253	Planting and estab\Stock\Quality	'*We don't grow any trees on site, we bring all our trees in. So someone else goes through the heartache of losing trees and trying to grow trees.*' - O - 1
254	Planting and estab\Stock\Quality	'*I currently am doing a business review which will be undertaken in the first 6 months of next year. We carry out the same process they have been doing for a number of years.* *What they do is set up a partnership agreement with tree suppliers, to ensure they get good stock.*' - W - 2
255	Planting and estab\Stock\Quality	'*At the moment its best practice planting, and species selection, and also quality of stock, is about all we can do at the moment.* ' - O - 6
256	Planting and estab\Stock\Quality	'*Getting some good quality trees, different stuff, not the same old thing*' - O - 6
257	Planting and estab\Stock\Rocket pot	'*All our stock is contract grown, we don't have our own nursery. We buy a lot of our trees from Adelaide Advanced at Cherry Gardens-all grown in rocket pots. We tend to find rocket pots are very good. Your root systems are not girdled, quite well structured. More important to us in the natives, in exotics it's not such an issue, we notice that the natives definitely grow better, establish better out of the rocket pots than in the hard balled tubs. Definitely some merit in them.*' - E - 3
258	Planting and estab\Stock\Nursery	'*We produce trees in our own Council nursery, and that's based around quality control.*' - W - 6
259	Planting and estab\Establishment\General	'*The species of trees that we plant. And the management then thereof –like pruning, maintenance.* ' - E - 1
260	Planting and estab\Establishment\General	'*Well defined management, maintenance practices during establishment.*' - E - 2
261	Planting and estab\Establishment\General	'*At the moment its best practice planting, and species selection, and also quality of stock, is about all we can do at the moment.*' - O - 6
262	Planting and estab\Establishment\General	'*Plant it properly, look after it and you get a good result in a timely fashion.* ' - O - 6

263	Planting and estab\Establishment\Fertilizer	'*We were using a bit of fertilizer type seaweed extract. Just in initial establishment. Just to hopefully give them a bit of a boost. Some of the heavier clays lock up their nutrients. So hopefully that will give them a bit of longevity. Not chloritic as they sometimes are-glow in the dark almost. Hopefully these little bits and pieces build up for good results for the tree.*' - E - 3
264	Planting and estab\Establishment\Form pruning	'*Good formative pruning from an early stage helps a lot. We try and get around to all our young trees and prune them within the first few years to establish a good framework and canopy structure.*' - W - 5
265	Planting and estab\Establishment\Watering regime	'*To support the planting of trees we have allocated watering trucks-we have 5 watering trucks. We have a very comprehensive watering program, which is broken down into-the sandy soils, we water trees for probably 3 years. With the clays, and other areas, we may have to only water the trees for 2 years.*' - W - 6
266	Planting and estab\Establishment\Watering regime	'*The guys that are involved in doing the watering are actually involved in the follow up watering. Seasonal factors. These are example of watering for 05/06, 06/07, 07/08. What Bruce is saying is that in the areas where you've got clay pan or clay based soils you water1-2 years, but on the sandy soils we're watering for 3 years now. Probably over the last 5-6 years with the drought some of those areas on the Peninsular we are maybe watering for a 4th year.* ' - W - 6
267	Planting and estab\Establishment\Watering regime	'*Our watering practices are good. We water our trees for the first 4 years from planting to establish the basis of good root stabilization and growth.*' - W - 5
268	Planting and estab\Establishment\Adopta verge	'*Another thing we do is we have a program called adopt a verge. We go into a sort of partnership with the resident. We mulch the nature strip and provide plants. There's still room to improve it because different people want to do different things with the verge. It starts to get mismatching. If you could get a whole street done like that it would be quite successful. It's trying to find a street that will get into it. Everyone's now panicking about having to use water on it. Now they're looking at let's adopt a verge.*' - E - 3
269	Planting and estab\Establishment\Guidelines\Existing	'*We have devised some planting specifications, for staff, particularly for small stuff-and that's for planting and small tree maintenance.* *So we get that consistency about street tree planting detail. We try to make it generic. We have small a tree maintenance detail. It just encourages some thought. And also discussions amongst staff so that they have the opportunity to comment about what they see or do. So that's where we have been going more recently.*' - W - 1
270	Planting and estab\Establishment\Guidelines\Existing	'*And Damian has specific planting details for reserve planting, but we've tried to adapt it to the street environment.*' - W - 1
271	Planting and estab\Establishment\Guidelines\Existing	'*And to some extent we've received that consistency in it through field staff*' - W - 1
272	Planting and estab\Establishment\Guidelines\Existing	'*Even a simple thing, Chris gave the gardeners a training session on street tree planting. Something simple like that has made quite a difference.* *Not really super advanced. This is pioneering.*' - O - 6
273	Planting and estab\Establishment\Guidelines\Proposed	'*Next part of the strategy is to create some design guidelines and maintenance requirements.*' - W - 3
274	Planting and	' *That will look at things like WSUD opportunities and*

	estab\Establishment\Guidelines\Proposed	*details-so passive irrigation*.' - W - 3
275	Planting and estab\Establishment\Guidelines\Proposed	'*A review of planting practices. We've currently got a Depot team. Within the organisation we've got the Australian Business Excellence Framework. And periodically teams are developed with particular projects that are identified. One of the most recent ones we have identified has been our tree planting practices. So we are quite open to review, of what we are doing and how we are doing it.*' - E - 5
276	Planting and estab\Establishment\Guidelines\Proposed	'*We've only got the one depot, but prior to the last 3 months we haven't had a works supervisor for the team leaders. So a lot of our on ground practices in last year have been quite segmented to 3 team leaders in 3 different areas, 3 different ways of doing things. We've made a lot of ground in the last year getting an approved, coordinated approach to handling a lot of the horticultural and arboricultural issues.*' - E - 5
277	Planting and estab\Establishment\Guidelines\Proposed	'*In collaboration with the Maintenance Team I am currently working on the development of tree planting guidelines including suggested species and preferred planting practices.*' - O - 2
278	Planting and estab\Establishment\Guidelines\Proposed	'*As a Landscape Architect, I am prepared to push the boundaries a bit and explore something a bit different and I'm also keen to work with the Maintenance Team to develop effective planting and management practices. The Planning Department also has a big role to play in applying conditions to developments to ensure adequate space for street trees.* ' - O - 2
279	Planting and estab\Establishment\Guidelines\Proposed	'*The Planning Department also has a big role to play in applying conditions to developments to ensure adequate space for street trees.* ' - O - 2
280	Planting and estab\Establishment\Guidelines\Proposed	'*Below ground, I used some of the stuff from a Treenet seminar a couple of years ago-I picked up a nice little booklet that is really interesting. It changed my thinking a little bit. The standard best practice tree planting detail*.' - E - 7
281	Organisational\Forward planning	'*I currently am doing a business review which will be undertaken in the first 6 months of next year.*' - W - 2
282	Organisational\Forward planning	'*We carry out the same process they have been doing for a number of years.*' - W - 2
283	Organisational\Forward planning	'*And we have a documented street tree planting program. That probably needs to roll over into more of a strategic plan in liaison with our policy unit*.' - W - 6
284	Organisational\Forward planning	'*Part of that covers our plan for the future.*' - W - 4
285	Organisational\Forward planning\Quantity	'*In the Management Strategy we talked about prolonging- more time to plan and reduce the number of tree plantings undertaken per year. This is in recognition of residents being reluctant to take out trees. So we need to maintain them longer.*' - E - 2
286	Organisational\Forward planning\Quantity	'*When I moved here I thought tree management was abysmal. Council supported tree coverage, and put funding in, but they weren't doing it well. We have now scaled it back in my 8 years here. Council used to be intent on putting as many trees in as it could, but not providing follow up management.*' - E - 2
287	Organisational\Forward planning\Quantity	'*Its even more important now. If Council can't put funding into watering trees, then they are wasting money planting them. So this season there was no 2nd generation tree planting, only interplanting. This*

		may continue next year also. I don't want this organisation to be burdened with having to maintain an excessive number of street trees, but doing it poorly. That doesn't benefit anyone.' - E - 2
288	Organisational\Forward planning\Quantity	'*And try to plant where there is a reasonable amount of open ground. And in some cases not go so crazy with numbers. With a street where you could probably get 20 in, and have problems with overshadowing of each other or being too tight, we are trying to get it down to15, and get 15 good trees. So we're looking at rationalization.*' - E - 3
289	Organisational\Forward planning\Quantity	'*We have a staffing problem as well. So we used to try and plant as many trees as we can, but we could never manage or maintain them. So about 5, 6 or 7 years ago we pulled back on our tree planting, because we never had the resources to manage them. So we reverted back to virtually replacements. It got to the stage that we couldn't even water them to keep them through their first summer.*' - O - 1
290	Organisational\Forward planning\Quantity	'*But we have restructured, and employed 3-4 extra people.*' - O - 1
291	Organisational\Forward planning\Quantity	'*Years ago the Councils used to go out and plant thousands of trees, but there was no vision. It was just meeting the numbers, some weird target. We don't go out with the view to planting millions of trees, we go out with the view to having a structured, well developed program that's going to meet the needs of the developing streetscape. We want resilient, sustainable, attractive trees that are not going to damage infrastructure and at the same time the trees are going to beautify the streets and the residents are going to be happy with them. That's part of our customer service focus.* ' - W - 6
292	Organisational\Forward planning\Succession planning	'*And then with regard to removals. We find it's a lot harder these days. Say you've got an old street of spathulatas. We'll try to speed up the removal process because these trees are at the end of their useful streetscape life. We won't replant with spathulatas, they are an inappropriate species an absolute pain due to branch failures. We had a massive program going back 10-15 years ago, where we worked in conjunction with ETSA. Due to the fact that the spathulatas were causing a lot of problems with their (ETSA) infrastructure. We had a program where we worked together to remove them to remove spathulatas and to replant with a more suitable species.*' - W - 6
293	Organisational\Forward planning\Succession planning	'*One Councilor wants amount of trees approved for significant tree removal each year-he wants us to plant at least that many back in, in our area.*' - E - 6
294	Organisational\Forward planning\Succession planning	'*We have about 3,600 street trees and we work on 3% turnover each year if we can.* ' - E - 7
295	Organisational\Forward planning\Succession planning	'*The logic behind that is that I calculated that if we stuck to 3% we would always have that ongoing urban stock. If you drop below that then you are going to reach a point where you will have to spend a lot of time and effort to catch up. Working on an average life cycle. It was more for economics than anything, to make sure we didn't get caught out with a high peak at some stage. Now we have got caught out, the drought has thrown the figures out. We were*

		going through and planting 500 trees in one year, because we were down. We've caught up now and around 150 is the average. We are, or were, actively seeking out some of the poorer trees that would cause problems. It was tough to find them but now it's easy because the drought really takes the deadwood out. And we are getting a bit more skilled now at finding the trees in decline. Especially with the Golden Rains where there's a pattern of leaf loss in successive seasons. We had some Golden Rains blow over on us-the root structure was gone. So we thought, if that's going to happen, we need to be a bit more proactive and started to take them out, and we haven't had one blow over since.' - E - 7
296	Organisational\Planning dept	'*That's one of the disappointing thing about planners, the amount of compromise you see going on, and half the time it to make life easy. It's all those grey areas and conflicts. You want to screen things off, there are complaints about safety issues, people can hide and jump out.*' - O - 6
297	Organisational\Planning dept	'*And space, to allow more trees you need more space. And that's what developers don't want to give you, as space is money. We need to plan areas of space for trees in these developments. The Divine site. Blocks are too small so we will probably go back through planning and say can you change that block into a reserve.* ' - O - 6
298	Organisational\Planning dept	'*I'm fighting against the fact that 2 of the 3 reserves on that development have got stormwater detention basins, and the planners say they will be filled with water so little it will be fine. Why? The design requirements for a detention basin limit the recreational opportunity you can have in that spot. They are quite happy to let them get away with that doubling up. They are right at their 12.5% now with the detention basins in 2 of the 3 reserves. Divine squeeze as much on as they can, the least creative thing you can come across. The planners are too happy to roll over as they don't see the importance of trees or reserves. The senior planners too-they just want to flick it on because it's easier.* *People that make the decisions on trees need that consciousness. It's a low priority for planners. I think in their curriculum they need to have a module or two on trees.*' - O - 6
299	Organisational\Planning dept	'*Its all about design, it needs to get sorted out and understood in the design phase. And the problem with trees, because they are the last thought it isn't done. And get it into specifications, because planners get a bit wishy-washy if it's not. Need to get it into engineering specifications so its mandatory-none of this-it would be good but you don't have to if you do this instead.*' - O - 6
300	Organisational\Planning dept	'*The Planning Department also has a big role to play in applying conditions to developments to ensure adequate space for street trees.* ' - O - 2
301	Organisational\Other internal\Innovation	'*Its early days for me at Council but we have a fairly fresh, new team and as we work through the existing backlog of design work, we can start to apply some new ideas at the planning stage and incorporate them in to the budget.*' - O - 2
302	Organisational\Other internal\Collaboration	'*We had a healthy discussion, developing this*

		Sustainable Landscape Strategy. It was over the things Council's could do, widening verges, roads and that sort of stuff-are we doing that, and should we be doing that. ' - E - 6
303	Organisational\Other internal\Priority	'*Its all about design, it needs to get sorted out and understood in the design phase. And the problem with trees, because they are the last thought it isn't done. And get it into specifications, because planners get a bit wishy-washy if it's not. Need to get it into engineering specifications so its mandatory-none of this-it would be good but you don't have to if you do this instead.*' - O - 6
304	Organisational\Other internal\Priority	'*mainly infrastructure constraints. The amount of area we have got to work with, and trying to flip it around so the first thing that's thought of is, we need to get trees into this street, how are we going to design the road. We're on the way but still very much the last thing that's done is the arborists are asked to come in and plant trees, once the infrastructure works are finished.*' - E - 6
305	Organisational\Other internal\Priority	'*We're getting there, working on it, lots of positive gains being made, but I don't think it will ever flip right around.*' - E - 6
306	Organisational\Other internal\Climate change	'*So that's something we're addressing in our climate change adaptation plan that we've just started working on.*' - E - 1
307	Organisational\Other internal\Knowledge	' *And the other thing is, if you have a problem, not being too shy to ring up someone and ask them. Sometime's someone's knowledge is better than reading 10 books.*' - W - 6
308	Organisational\Other internal\Training	'*Even a simple thing, Chris gave the gardeners a training session on street tree planting. Something simple like that has made quite a difference.* *Not really super advanced. This is pioneering.*' - O - 6
309	Organisational\Developers\Master plans	'*And the criteria for all of that-we also make sure that people who do the work within our Council area, namely developers, that they adhere to that.* ' - W - 6
310	Organisational\Developers\Master plans	'*A developer can't just go and plant a street and think this is it. What we have to do is assess the plans they forward. We make developers do Master Plans for all of the sites they are redeveloping. And that's generally working in coordination with the landscape architect who they nominate. And that's been a good process, because we get some good streets developed.*' - W - 6
311	Organisational\Developers\Master plans	'*And we sign off on these plans. There's a specification for planting with is quite detailed. There's a specification for the actual planting by the contractor. There's a specification for the supply of the trees. Before the trees are allowed to go on site the landscape architect sights the trees so we don't get any poor stock and we just end up with problems*' - W - 6
312	Organisational\Developers\Bonding	'*And at the time of land division we bond accordingly-and the mechanism for that is the release of titles. So once they apply to release titles and sell lots we will bond for every little lot and amount to secure the trees. It's the only opportunity we have otherwise there's no-I think there might be some principles in our Development Plan but they are pretty flimsy,*

		around street amenity. I don't know if they specifically mention street trees. But don't go to the Development Plan to force any landscape outcomes. In the worst case scenario you have the ERD court and you are on a hiding. All you have is the 12.5% open space requirement. ' - O - 3
313	Organisational\Developers\Bonding	'*Its really up to negotiating for separate stuff, seeking securities at the time of release of titles. So that goes for reserves generally, you seek to bond to get some outcome. Ideally Council are much better at negotiating, in general terms or coming up with some specific agreement. Particularly Playford North where we are dealing with partners, with LMC-so we try to iron out all these issues in documentation up front. Particularly it's an issue where super lots are created. And you end up dealing with the Divine's, the Delfin's, whoever, we aim to have some quite rigid guidelines around landscape development.* ' - O - 3
314	Organisational\Developers\Bonding	'*In the past trees have not been bonded, it's something we've discussed that we would like to implement over the next couple of years.* ' - O - 4
315	Organisational\Developers\Bonding	' *All the legal advice you get is you can't, yes you can take a small fee but it doesn't end up substituting for the cost of what it does to replace and maintain a street tree.* ' - O - 4
316	Organisational\Developers\Bonding	'*But we don't always get the opportunity to control how developers install trees, complying with their development approval, sometimes they choose to install them themselves on the basis of saving costs, but inevitably the saving of costs means the loss of a tree. In the past trees have not been bonded, it's something we've discussed that we would like to implement over the next couple of years.* ' - O - 4

Factors Preventing Adoption of Practices

No	Category	Commentary text
1		In terms of asset management generally-you have all this stock that comes to the end of its useful life at once, and you also have to acknowledge that trees also have a useful life.
2	Organisational\Resources\General	'*I think resources.*' - W - 1
3	Organisational\Resources\Funding	'*At the end of the day, it would probably go down to costing. Cost is always a factor. But I don't think it's going to limit us.* ' - E - 3
4	Organisational\Resources\Funding	'*Funding.*' - W - 2
5	Organisational\Resources\Funding\Budgets	'*Probably budgets certainly. Most Council budgets are based on historical tradition. Trying to get new improved changes through which come with budget implications is quite difficult as the long term financial plans are often set in stone .So the conflict there is do you cut back on what you do to provide a better outcome, or provide a greater number but potentially at a lesser quality.*' - W - 3
6	Organisational\Resources\Funding\Cost	'*I guess also cost would be the other thing. Ultimately the cost of what would be a best practice, or the best management, or the best street tree planting program or pruning practice*' - E - 5
7	Organisational\Resources\Funding\Cost	'*Cost.*' - O - 3
8	Organisational\Resources\Funding\Maintenance	'*The lack of resources for small tree maintenance.*' - E - 2
9	Organisational\Resources\Funding\Maintenance	'*The lack of resources for small tree maintenance. ????*' - W - 1
10	Organisational\Resources\Funding\Best	'*I think you can put the right practices in place with whatever*

	practices	*budget you've got-its just being smart about how you go about doing it.*' - E - 1
11	Organisational\Resources\Funding\Best practices	'*For example instead of having individual little raingardens for each tree, you might have big blocks of it or something like that. You just have to do it efficiently.*' - E - 1
12	Organisational\Resources\Funding\Best practices	'*I don't know if those practices necessarily need to cost more?*' - E - 1
13	Organisational\Resources\Funding\Best practices	'*I guess also cost would be the other thing. Ultimately the cost of what would be a best practice, or the best management, or the best street tree planting program or pruning practice.*' - E - 5
14	Organisational\Resources\Funding\Still plant trees	'*Money?. It's not that-if the organisation thinks it is important it will find the money, move it from other budget areas.*' - E - 2
15	Organisational\Resources\Funding\Still plant trees	'*At the end of the day, it would probably go down to costing. Cost is always a factor. But I don't think it's going to limit us. We just won't plant as many. I'm a firm believer in doing it properly, do it once. I try to foster that into the guys. It is a long term asset so if we put the TLC into it for the first 3 years we are going to reap the rewards. If don't do everything that's arboriculturally or horticulturally accepted, there's no reason why it shouldn't flourish. Not flourish but survive through to maturity. And not cause any major conflicts to infrastructure and people alike.*' - E - 3
16	Organisational\Resources\Funding\Still plant trees	'*But nobody is going to get up and say they don't want trees-unless it conflicts with what they are doing.*' - W - 4
17	Organisational\Resources\Staff\Training\General	' *The biggest obstacle is removal of current day staff that don't respond to training or development. This prohibits replacement with skilled enthusiastic tradespersons.*' - W - 6
18	Organisational\Resources\Staff\Training\General	'*Also - currently there doesn't seem to be highly skilled staff coming out of the horticultural education system.* ' - W - 6
19	Organisational\Resources\Staff\Training\General	'*I've tried training at the depot. It's a cultural thing as is often the case these days. It's a matter of getting to them to actually understand.*' - E - 7
20	Organisational\Resources\Staff\Training\Turnover	'*Turnover of staff is an issue for us. It's not the high turnover of staff, it's actually the turnover of the induction process. Where they to know Council's rules and regulations but not the finer things-specifications for other depots. The Planning Department also.* ' - W - 1
21	Organisational\Resources\Staff\Training\Turnover	'*Its difficult because the minute you get someone on the right track they leave-its a never ending battle.*' - E - 7
22	Organisational\Resources\Staff\Training\Contractors	'*Educating contractors-there's a bit of a problem for us to establish trees. We need to be available to give appropriate advice regarding street trees. So specifications for contractors. Having tree protective measures on plans-for our engineering department, predominantly around larger trees. So being involved from my perspective in the early stages of design. And encouraging that with open space too.* ' - W - 1
23	Organisational\Knowledge\General	'*Probably just knowledge.*' - E - 1
24	Organisational\Knowledge\General	'*Incomplete knowledge.*' - E - 4
25	Organisational\Knowledge\General	'*Lack of data.*' - E - 4
26	Organisational\Knowledge\General	'*The main thing again is the consciousness and priorities.*' - O - 6
27	Organisational\Knowledge\General	'*Awareness.*' - O - 3
28	Organisational\Knowledge\General	'*Education.*' - O - 3
29	Organisational\Knowledge\Data base	' *And getting the information that is available to us. Information on our trees, our tree condition, our tree health, keeping that information up to date.* ' - E - 5
30	Organisational\Knowledge\Engineers	'*And educate the engineers too about how they can modify a few areas of their design to accommodate your design. And here they are open to different ideas.*' - E - 1
31	Organisational\Knowledge\Engineers	'*Need good engineers to show them. Some good WSUD engineers-Joe at Tonkins has done a Masters in WSUD.*' - E - 4

32	Organisational\Knowledge\Engineers	'*Education …Information needs to be consistent and directed at the engineers and managers together with our elected members. If you have them on board you have a better understanding and a more sympathetic ear.*' - W - 5
33	Organisational\Knowledge\Best practices	'*Its about knowing where to get that information from.*' - E - 1
34	Organisational\Knowledge\Best practices	'*How it all works. Are there other Councils undertaking these practices that you can get information from.*' - E - 1
35	Organisational\Knowledge\Best practices	' *And information on what we can do to improve our practices out there. What is current best practice.*' - E - 5
36	Organisational\Knowledge\Best practices	'*What is regarded as best practice – WSUD, wider verges?*' - O - 2
37	Organisational\Knowledge\Best practices	'*And I guess best practices. What is best practice, it doesn't seem to filter out sometimes. If it is best practice, there's always someone willing to jump up and say they don't agree with it. So there always seems to be this dispute about what is the best way to go about putting a tree in.*' - E - 7
38	Organisational\Knowledge\Benefits education\Strategic level	'*Education …Information needs to be consistent and directed at the engineers and managers together with our elected members. If you have them on board you have a better understanding and a more sympathetic ear.*' - W - 5
39	Organisational\Knowledge\Benefits education\Strategic level	' *Then you could start putting into practice some better alternatives with funds that have been made available to you.*' - W - 5
40	Organisational\Knowledge\Benefits education\Asset mgrs	'*The perception is that there is no dollar value in trees. However there's a lot of work being done in that area and things are changing. If a relationship can be demonstrated between higher land prices and the presence of trees then we have a financial argument that may appeal to the bean counters holding the purse strings.*' - O - 2
41	Organisational\Knowledge\Benefits education\Asset mgrs	'*Unfortunately if they keep thinking of trees as a second rate asset, it will never get better. There is an irony. Asset management consists of the register of all councils assets but the first thing that is generally audited are all street signs and poles rather than trees as a priority. They just don't realize the potential of the living asset, which is a real shame. The sooner managers realize the benefits of trees the better off we'll all be.* ' - W - 5
42	Organisational\Knowledge\Benefits education\Asset mgrs	'*Trees are seen as being a negative impacting on infrastructure, which is crazy. They have this issue with concrete which must be straight, and bitumen that must be flat, and anything that alters that material is viewed as a bad thing. They should be looking at alternatives and making those materials more flexible to accommodate our living assets.*' - W - 5
43	Organisational\Knowledge\Benefits education\Asset mgrs	'*If trees weren't as flexible as they are they would all break/collapse within the first 12 months of being planted, because they would snap. The strength and beauty of trees is that they will grow and adapt to their environment, they are flexible. By not stringently staked and allowing movement, once trees have established their roots and their structural muscle if you like, they have laid their foundations for a long existence. If engineers were as flexible as trees we may get better outcomes. Arborists realize the flexibility and capability of a tree to adapt-even with failures and problems. It's just people that aren't willing to give trees that benefit. People don't like change or adapt to new ideas very well.*' - W - 5
44	Organisational\Knowledge\Benefits education\Community	'*The other one is residents-getting them to change. And to understand what we are trying to achieve. It takes time, that's the real problem.*' - E - 7
45	Organisational\Knowledge\Benefits education\Community	'*Maybe the answer is committing to one particular project and showing that as an example, you set the trend from that point on. It never ceases to amaze me how people have differing views on trees.*' - E - 7
46	Organisational\Knowledge\Benefits education\Community	'*Old people are obsessed with mess. We've got one beautiful reserve with 6 big gums. And she lives on NE side of the reserve and she cops the south-westerly's blowing, putting leaf litter in her*

		driveway. She rings me this time of year almost weekly to take the trees out.' - E - 7
47	Organisational\Knowledge\Benefits education\Community	'*Just getting that change.*' - E - 7
48	Organisational\Knowledge\Benefits education\Demo projects	'*Maybe the answer is committing to one particular project and showing that as an example, you set the trend from that point on. It never ceases to amaze me how people have differing views on trees.*' - E - 7
49	Organisational\Knowledge\Benefits education\Demo projects	' *Then you could start putting into practice some better alternatives with funds that have been made available to you.*' - W - 5
50	Organisational\Management practices\Responsibility	'*That sort of thing that can undo so much good work. But I really think that at the of the end of the day its probably more ourselves. Particularly in this Council where there is so much support for tree planting.*' - E - 5
51	Organisational\Management practices\Responsibility	'*From a Council perspective, only ourselves prevent or limit the adoption of the practices.* ' - E - 5
52	Organisational\Management practices\Time	'*From a Council perspective, only ourselves prevent or limit the adoption of the practices. Probably our only limitation is ourselves, and possibly the time we put towards it. Competing interests.*' - E - 5
53	Organisational\Management practices\Time	'*The other thing is being bogged down in the day to day issues rather than your forward planning approach. The sad truth of life really across all domains, not just trees.*' - E - 5
54	Organisational\Management practices\Contract admin	'*Contract administration-invariably the landscape architect might provide a service to a developer and never be called upon again. Thanks very much, we've got the approvals, see you later. And you have the contractors just running the whole show as they see fit. Again there's the responsibility for Council in that, to ensure that those approvals are met.*' - O - 3
55	Organisational\Management practices\Eng priority	'*The main thing again is the consciousness and priorities.*' - O - 6
56	Organisational\Management practices\Eng priority	'*Just an example of what you are up against-unless you can get in with some good advice was only a year ago that development at Chiton, the old St Ive's church site-with palm trees. That landscape plan was approved by Council. An embarrassment. And the next one at Middleton Shores-their landscape plan approved by Council had Acacia saligna. I was trying to get them to remove them. Couldn't get them to do it as Council had approved the plan. Simple things like that, that are so glaringly wrong. People treating trees as an afterthought and not getting any professional advice on how to do it properly.*' - O - 6
57	Organisational\Management practices\Eng priority	'*The general civil design culture, not to consider alternatives to the generic run of the mill process and methods. There are situations where nothing else can be done because of traffic volumes or something else, but if you consider the way the verge is treated the trees can benefit as well.*' - O - 4
58	Organisational\Management practices\Eng priority	'*Obviously engineering. Engineers could. It's an emphasis on engineering as a priority could have an effect.*' - E - 6
59	Organisational\Management practices\Eng priority	'*But I think more and more these days the engineering people work with the arborists and the arboricultural people.*' - E - 6
60	Organisational\Management practices\Eng priority	'*A reliance on infrastructure could prevent it.*' - E - 6
61	Organisational\Management practices\Eng priority	'*There's a huge push in local government for asset management plans at present. That's about maintaining your assets. Its fundamentally hard infrastructure related. I'm not sure trees even have to be looked at as part of the asset management plan. So there you are almost going against what the arborists and horticulturists want, which is that priority given to trees.* ' - E - 6
62	Organisational\Management practices\Eng priority	'*So what you are almost doing Potentially by having Asset Management plans you are putting the emphasis back on your hard assets-your roads, footpaths, kerbs and water tables.*' - E - 6
63	Organisational\Management practices\Eng priority	'*I think it's a testing time over the next 5-10 years for the urban forest* ' - E - 6
64	Organisational\Management	'*We are like most Councils-the priority has been on the*

	practices\Eng priority	*engineering focus. Trying to flip that around. It's the big challenge that we face.*' - E - 6
65	Organisational\Management practices\Change resistance	'*Conservative nature of local government-in terms of what ifs and finances. Legitimate concerns, need data.*' - E - 4
66	Organisational\Management practices\Change resistance	'*The problem I've found here is there's resistance to change.*' - E - 7
67	Organisational\Management practices\Change resistance	'*A good example, we had one road in the area with a high crown, very deep old stone gutters, extremely high bluestone kerbing. You couldn't get out of the car unless you parked a metre or so out from the kerb. Our aim was to narrow the pavement down, give more room for the trees and rebuild the roadway. I just succeeded in narrowing it down and rebuilding it.. I didn't succeed in putting roundabouts in. They were just so negative to change. So I guess what I am saying is the exercise at Unley (Windsor Street) probably wouldn't work here, it would be far too radical for a lot of the residents.* ' - E - 7
68	Organisational\Management practices\Change resistance	'*But having said that, times have changed. And that project was 4 years ago. We actually irrigated reserves 4 years ago, we don't do that anymore and we don't get complaints about it. So maybe if I can sell the right way-I could come up with concept design that narrows the road down, allows for parking on one side, even if we rearrange the side on which the planting is, and incorporate within that some sort of retention/detention of water. It would be a winner.*' - E - 7
69	Organisational\Management practices\Change resistance	'*But again it has to be in a style that is consistent with the character of the area. That's tough.*' - E - 7
70	Organisational\Management practices\Specs	'*Its got to be mandatory-in the specifications.*' - O - 6
71	Organisational\Management practices\Specs	'*If its written in the legislation somewhere people accept it. It's like anything, you wear seat belts because you get fined if you don't.*' - O - 6
72	Organisational\Management practices\Specs	'*Your building costs have gone up in some instances because you need to meet new standards, once it's in law you do it. Its accepted because it's a legal obligation.* ' - O - 6
73	Externalities\Service authorities	'*However we always seem to fight with the service suppliers, the Origin's, ETSA's, Telstra's, the kerb and gutter guys.*' - E - 5
74	Externalities\Service authorities	'*That sort of thing that can undo so much good work*' - E - 5
75	Externalities\Developers	'*You can put a land management agreement on areas. But developers come and do what they want and then get out. Even if it's in black and white they can take us to court and get it tossed out.*' - O - 1
76	Externalities\Developers	'*Especially with significant trees, I don't know why we even bother, developers take no notice of it, and when it's all done and dusted it's hard for us to try and convince them that what they've done is wrong. We've had a few issues of late about that. Building houses underneath significant trees virtually.*' - O - 1
77	Externalities\Developers\Cost	'*I think it's the cost.* *When they build a subdivision, they want everything to be as cheap as they can possibly do to make more money. And we have trouble with developers, contractors all the time.* *I suppose you have got to change their way of thinking, from purely making money, to getting the best end result. We had a developer ripped out a whole beautiful bank of Gawler hybrids, because he wanted this new complex up. Of course he had no permission to do it, but once they were all gone, there's really nothing we can do about it. We tried to take him to court but didn't get anywhere. That was the new Homemaker Centre. Now we are having trouble trying to get them to re-landscape it. They're saying now it's on your land, it's for you to worry about, not us.*' - O - 1
78	Externalities\Developers\Cost	'*You can put a land management agreement on areas. But developers come and do what they want and then get out. Even if it's in black and white they can take us to court and get it tossed out.*' - O - 1

79	Externalities\Developers\Cost	'*I think cost is often the biggest one. The lot yield of areas by developers who want to maximize their yield. Because they are responsible for putting in the infrastructure, there's a huge cost of developing land. So that's the biggest issue, the financials.* ' - O - 2
80	Externalities\Developers\Cost	'*The developer's opportunity to make a buck I see as being a big one. They see the road space as minimal to provide movement through the site, so they can maximize land area. And not take into account the actual provision a street tree can provide financially back to the development. Where you have wider verges and a treed environment, it's amazing how the values tend to reflect a better provision financially*.' - O - 4
81	Externalities\Future liability	'*Trees will be a source of ongoing liability-have to be very careful now to get it right*.' - E - 2
82	Externalities\Future liability	'*Litigation could prevent it if we get more and more Americanized-have claims for people tripping on footpaths. One way to avoid having tripping points on footpaths would be to get rid of street trees. I'm not suggesting that would happen for one minute, or alternatively it could be about planting smaller trees, so you would lose your canopy of trees over the city*.' - E - 6
83	Physical\Future space	'*In that narrow strip of land we need space for a footpath, tree, bike path, car parking, services etc. Something has got to give. Space for tree planting suffers at the moment-will change in the next decades.* ' - E - 2
84	Physical\Future space	'*Pressure placed on trees in that road reserve. I love the thought that petrol prices will go up, resulting in less pressure on Council to provide good roads. But now people expect a minimum of a double garage and space to park another 3-4 cars. In coming decades people will expect more room for cycle paths. Could have narrower streets*.' - E - 2
85	Physical\Future space	'*People will shift. They will see that the housing style now is short sighted. People will see the need for open space. Gardens are getting smaller so there will be greater expectations on Council for open space. Council will look at the street and verge as an opportunity. Techniques will improve in the installation of services to reduce tree conflicts-common service trenching etc*.' - E - 2
86	Physical\Species range	'*And the technology is not advanced enough to give us enough variety of species*.' - W - 2
87	Physical\Species range	'*That culture of replacing like with like is also another thing, in terms of retrofitting, and its effect on established trees*.' - O - 4