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treenet

Proceedings of the

11th National Street Tree Symposium 2010

Government of South Australia

Department for Transport, Energy and Infrastructure

TerraCottem

ARBORtrack

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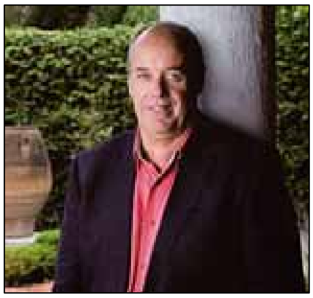
SPEAKER PROFILES



NIGEL TAPPER

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Professor Nigel Tapper holds a Personal Chair in Environmental Science at Monash University where over the last 10 years he has variously served as Head of the School of Geography and Environmental Science, Foundation Director of the Monash Sustainability Institute (a key University research institute responsible for facilitating and coordinating Monash-wide research across the key themes of Climate, Water, Energy, Biodiversity and Transport), and Joint Coordinator of the Monash Atmospheric Science Program. He is currently on the Executive of the Monash Centre for Water Sensitive Cities and the Implementation Committee of the Victorian Centre for Climate Change Adaptation Research.

Nigel has been actively involved in the work of the IPCC over the last 10 years and is currently a Member of the IPCC Expert Panel on Infrastructure and Settlements. Nigel has an active research program in surface-atmosphere interaction, climate change adaptation and mitigation, and climate impacts, especially as they relate to urban environments, human health, dust and fire. He is well known for his work on the meteorology and climatology of Australia's arid zone and seasonally wet tropics and for his collaborative work on the climate dynamics of the maritime continent.

Nigel is co-author of the classic text on Australian climate and weather, and recently co-edited Bridging Wallace's Line: Environmental and Human History and Dynamics of the Southeast Asian-Australian Region. He has also had two other books, ten book chapters and over 120 research publications in an academic career spanning nearly 30 years. He has held ARC competitive funding almost continuously since 1985.

CHRIS DANIELS

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Chris Daniels is Professor of Urban Ecology in the Division of Information Technology, Engineering and Environment at the University of South Australia. He is Head of the Discipline of Geospatial and Environmental Management, one of 4 Disciplines in the School of Natural and Built Environments in the Division of ITEE at UniSA. He is also Deputy Director of the Barbara Hardy Institute which is a major research Institute located primarily in the Division of Information Technology, Engineering and Environment, with as large research agenda focused on creating sustainable communities. He facilitates and conducts research into the relationship between humans, the communities we build and the natural environment.

Chris was educated at the University of Adelaide and the University of New England. Chris has held academic positions at the University of California, Flinders University and the University of Adelaide before accepting the chair of Urban Ecology at UniSA. He is married with 2 children and lives in Belair. He is a prolific publisher, with 8 books published or in press and over 120 scientific publications. In 2005 Chris, with Catherine Tait edited the Book Adelaide Nature of a City: Ecology which won the Whitley Award, in 2006 and which received a High Commendation from the Planning Institute of Australia in 2008. Adelaide Water of a City is the second in this series.

Chris teaches undergraduate and postgraduate zoology and supervises a large number of research students each year. He is a member of several journal editorial boards and zoological societies. He holds honorary positions at ZoosSA and the SA Museum. Chris has always had an abiding interest in reptiles, particularly lizards, and is a passionate communicator to the general community, about science and the environment. Chris has a regular session on 891 ABC Radio and from this relationship Chris conducts field trips with ABC listeners "into the backyard" and has run "Operation" surveys over the past 4 years. He won the premiers science award for communication and education in 2007.

DR GREG MOORE

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Greg Moore was Principal of Burnley College of the Institute of Land Food Resources at Melbourne University from 1988 to 2007. Prior to this he had been a Senior Lecturer and Lecturer in Plant Science and Arboriculture at Burnley from 1979. He was Head of the School of Resource Management at the University from October 2002 to April 2007. Apart from a general interest in horticultural plant science, revegetation and ecology, Greg has a specific interest in all aspects of arboriculture, which is the scientific study of the cultivation and management of trees.

He is recognised internationally as one of the founders of the modern arboricultural movement and is widely sought after as a speaker, advisor, advocate and mentor. His keynote papers at past Treenet Symposia have been a major catalyst for the recent changes in attitudes and practices relating to Australia's urban trees. His presentations are founded on his exceptional ability to pass onto his audience his thorough understanding of the subject at hand.

As Chair since 2005, Greg's other major contribution is the orderly and efficient governance he brings to TREENET. His ability to think strategically and his wide experience in the management of not for profit organisations has been called upon to the benefit of many environmental and educational causes over the past 30 years.

He has contributed to the development of Australian Standards in pruning and amenity tree evaluation and has been a major speaker at conferences in Australia, Israel, Hong Kong, USA and New Zealand in recent years. He was the inaugural president of the International Society of Arboriculture, Australian Chapter. He has been a regular on Melbourne radio, particularly with ABC 774 and 3AW.

He has been a member of the National Trust of Victoria's Register of Significant Trees since 1988 and has chaired the committee since 1996. Greg has been on the Board of Greening Australia (Victoria) since 1989 and has been an active member of various sub-committees of that organisation. He was involved with the Agriculture and Horticulture subject at VCE level setting several of the examinations. He has also served on a number of industry and TAFE sector committees, especially those that deal with curriculum and accreditation matters. He is currently supervising eleven post-graduate students and continues to pursue an active research profile in any matters that relate to trees in the urban environment and revegetation. He has written one book, contributed to another and has had some 80 papers and articles relating to tree biology and management published.

MARTIN NORRIS

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After a recent restructure, Martin is now the Coordinator Open Space Planning and Support for Wellington Shire in Victoria. He has responsibility for a range of strategic and operational functions, in particular urban tree management. He has been employed within the horticultural and arboricultural sectors for the past 25 years, the last 21 years in local government.

He has finally handed in his Masters Degree thesis on the analysis of tree risk assessment methods and how they interact with assessors and is awaiting the examiners' comments. These studies have created a great deal of interest and he has presented at conferences and seminars across Australia and in New Zealand and the USA including the ISA International Seminar on Trees and Risk held at Bartlett Labs in North Carolina.

Martin is a member of the TreeNet Advisory Board, the Standards Australia committee drafting the Specifying Trees standard, is on the editor board of The Arborists News and has been a Director of ISAAC and ISA board member.

TONY HALL

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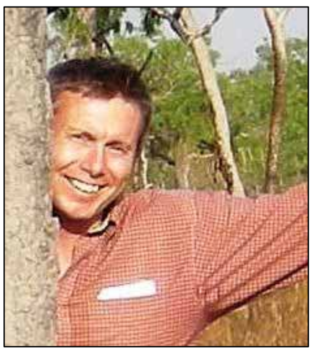
Tony Hall retired from the position of Professor of Town Planning Anglia Ruskin University, Chelmsford, UK, in 2004 and came to live in Brisbane. A specialist originally in transport planning and later in urban design, his academic career of over 25 years produced notable publications in the field of design guidance. Rather unusually, he also served as a local councillor and led Chelmsford's planning policy for seven years, achieving a government award for environmental quality in 2003.

He is now an Adjunct Professor within the Urban Research Program at Griffith University where he carries out research on sustainable urban form. In particular, he has carried out an investigation into the disappearance of substantial backyards in the newer Australian suburb, the subject of his latest book.

DR STEPHEN LIVESLEY



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Dr Stephen Livesley is a Senior Research Fellow of the Monash Sustainability Institute, affiliated with the School of Geography and Environmental Science. He has held research positions at The University of Melbourne, The University of Western Australia and the Department of Sustainability and Environment (DSE), Victoria.

Stephen's research interests aim to link ecosystem scale monitoring with soil and plant process studies of carbon and nitrogen cycling, to better understand and predict these processes under changing climatic and management conditions. A key focus has become the detailed and extended measurement of soil-plant-atmosphere exchange of CO_2, N_2O and CH_4 in relation to changing soil conditions and microbial processes (nitrification, denitrification, methanotroph oxidation, litter decomposition and soil C mineralization). This research has been applied to issues of land-use change, climate change, fire disturbance, and land management in agriculture, forest and urban systems. In recent years Stephen has been involved in developing urban biogeochemistry research capability in the University of Melbourne and now Monash University.

PHILIP HEWETT

Arboriculturist
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For some 30 years Philip has been engrossed in private and municipal tree administration in town planning, landscape and asset management and tree preservation. In 1986, after four years as Tree Officer for Hobart City Council he joined NSW TAFE where he gained his teaching qualifications and taught horticulture at Ryde College. Four years later he left for another bout of municipal trees this time at Wyong Council. He later established an arboriculture consultancy before returning for a third foray into local government, this time at Newcastle. Now semi-retired, Philip still widely promotes the importance of urban forest to our urban communities. His numerous public presentations derive from extensive practical experience at the working interface of public trees, Council administration and the communities they serve. Philip was appointed Acting Commissioner in the NSW Land & Environment Court in 2010.

FLEUR FLANERY

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Fleur Flanery is the Manager of ‘Open Space Planning’ for City Services with the Department of Territory and Municipal Services, ACT Government. She has a background in Landscape Architecture, Communication, and Horticulture. Prior to taking up her current role she worked at Greening Australia in their National Office and at Land & Water Australia, a Research and Development Corporation.

HOW TREES SAVE LIVES. THE ROLE OF A WELL WATERED LANDSCAPE IN LIVEABLE CITIES

Nigel Tapper
Professor of Environmental Science, School of Geography and Envir. Science, Monash University

MONASH University

How Trees Save Lives. The Role of a Well Watered Landscape in Liveable Cities

Nigel Tapper

Centre for Water Sensitive Cities and Monash Weather and Climate Program
School of Geography and Environmental Science
Monash University, Melbourne, Australia

(with acknowledgement to my colleagues in CWSC and MWCP)

Four Critical Truths in Relation to Climate Change and Urbanization

1. Climate change is now accepted as real and requires immediate development of strategies for mitigation and adaptation
2. Globally, the process of urbanization continues apace
3. Urban warmth (the urban heat island) is of similar magnitude to predicted greenhouse climate change during the 21st century (and is superimposed upon that greenhouse warming)
4. The physics of urban warming is well understood and can be mitigated, for example by maintaining water in the landscape

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Global Urbanisation

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Australian Urbanisation

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Other realities

1. Increasing evidence that climate extremes may be shifting MORE than the climate averages
2. Globally, there is a push for cities to become denser (urban consolidation) therefore hotter
3. In many places around the world (e.g. in Australia) national and urban populations are ageing
4. Water scarcity is becoming a major issue for many cities around the globe, especially in "Mediterranean" climate regions

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Australian Projected Temperature Changes to 2100

IPCC 4AR, 2007

~0.5- 1degC change last century
~2.5-4.5 degC change projected by 2100 under moderate emissions scenario

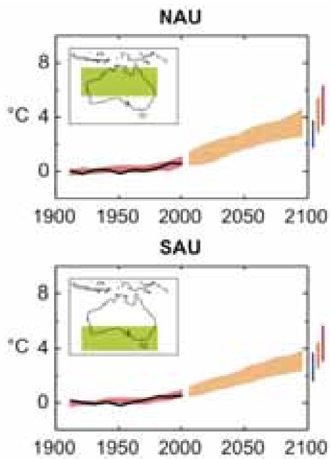

Figure 11.16. *Temperature anomalies with respect to 1901 to 1950 for two Australian land regions for 1906 to 2005 (black line) and as simulated (red envelope) by MMD models incorporating known forcings; and as projected for 2001 to 2100 by MMD models for the A1B scenario (orange envelope). The bars at the end of the orange envelope represent the range of projected changes for 2091 to 2100 for the B1 scenario (blue), the A1B scenario (orange) and the A2 scenario (red). More details on the construction of these figures are given in Box 11.1 and Section 11.1.2.*

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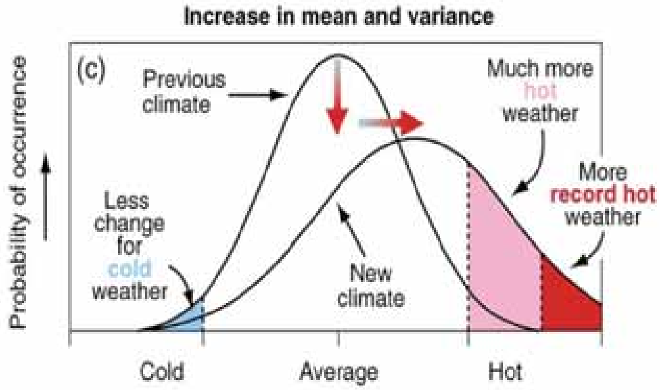

Another Issue - How Might Extremes Change?

IPCC TAR, 2001

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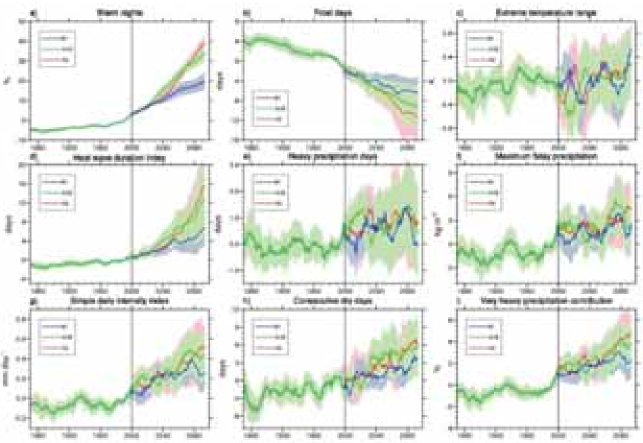

Time Series of Extremes for the Australian Region 1870-2099

Alexander and Arblaster, 2009

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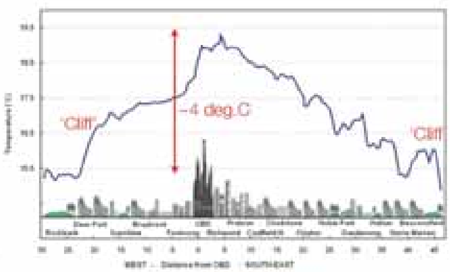
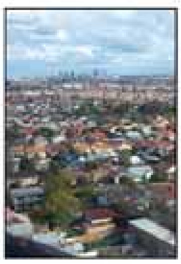
The Melbourne Urban Heat Island

0100h March 23, 2006





Coutts, Beringer and Tapper, 2010

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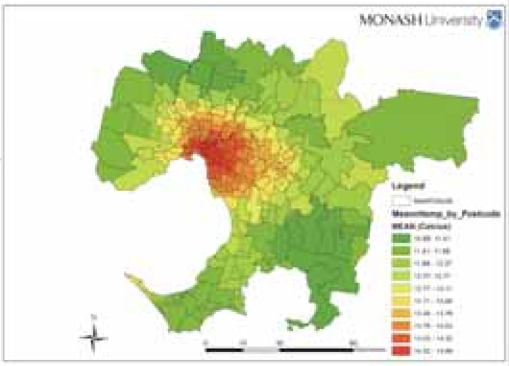
The Melbourne Nocturnal Urban Heat Island - MODIS Monthly Data 2000-2006

Loughnan, Nicholls and Tapper, 2009a



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Urban Radiation and Energy Budget Simply Explained

Radiative energy available at the surface (Q*) + artificially produced energy (F) = energy used in heating the air (QH) + energy used in heating materials (QG) + energy used in evaporating moisture (QE)

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Causes of Urban Warmth

- The nature of surface materials (i.e. thermal characteristics and colour (albedo) of surfaces)
- Surface shapes and structures (the complex nature of urban geometry)
- Alterations in urban air quality
- The presence of heat sources (cars, industry, space heating, metabolic heat, etc)
- Surface waterproofing and especially removal of urban storm water

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Field Observations:
The surface energy balance
3 urban sites of increasing housing density and
1 rural site as a control
The eddy covariance technique at urban sites
CO_2 also measured at 2 sites
Operated simultaneously for 3 months
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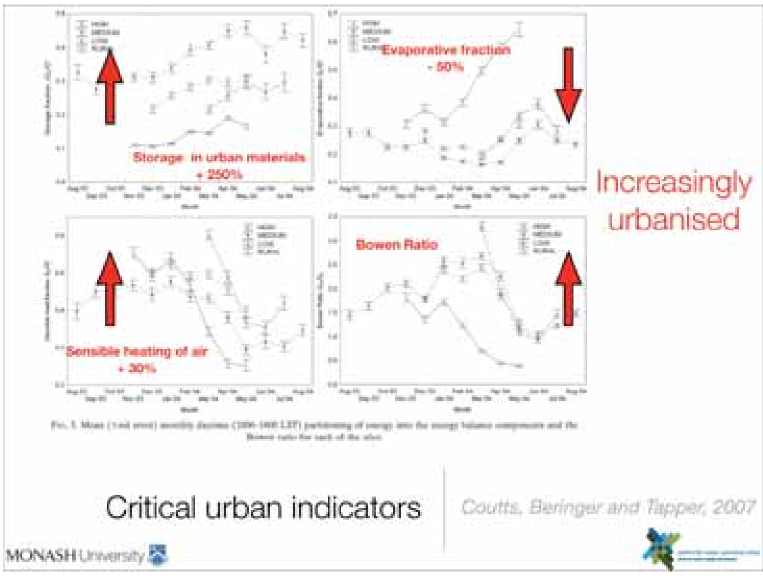
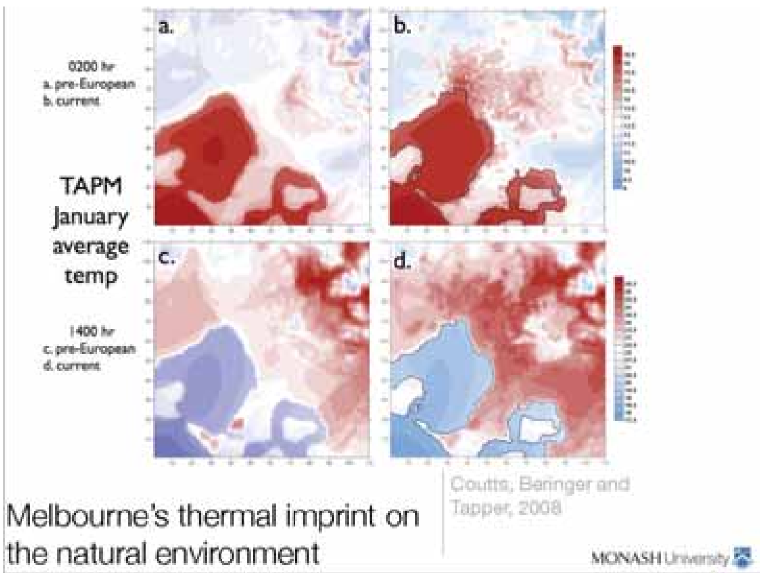
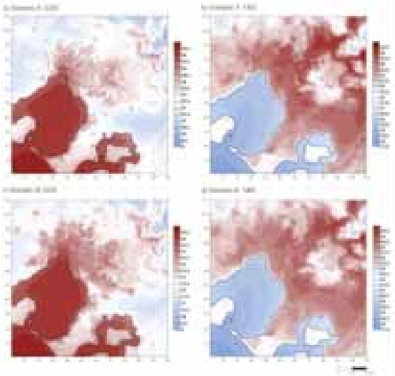

Storage in urban materials + 250%
Evaporative fraction - 50%
Sensible heating of air + 30%
Bowen Ratio
Increasingly urbanised
Critical urban indicators
Coutts, Beringer and Tapper, 2007
MONASH University


a.
b.
c.
d.
0200 hr
a. pre-European
b. current
TAPM
January
average
temp
1400 hr
c. pre-European
d. current
Melbourne's thermal imprint on the natural environment
Coutts, Beringer and Tapper, 2008
MONASH University

Modelling the Impact of Urban Consolidation on the Melbourne Heat Island - Melbourne 2030 Plan

Coutts, Beringer and Tapper, 2008

Mean surface temperature fields for 0200 and 1400, with current urban fabric (A) and projected urban fabric (B)



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Heat and human mortality

- **Definition** (no formal definition of heatwave)
  - BoM "prolonged period of excessive heat"
  - Largest cause of mortality natural hazard (BoM, Borden & Cutter 2009)
  - Passive threat - unlike floods/cyclones *and underreported*
- **Examples**
  - Most famous heatwave-mortality event Europe 2003
  - As many as 35,000 excess deaths were associated with the 2003 event
  - Beniston, 2004 *Geophys. Res. Letters* "..shape of things to come"
  - Australia smaller numbers (374 excess deaths in Jan09 heat wave event).
- **Place Specific**
  - Features of the natural and built environments affect heat loads
  - Demography, socio-economics and underlying health status important

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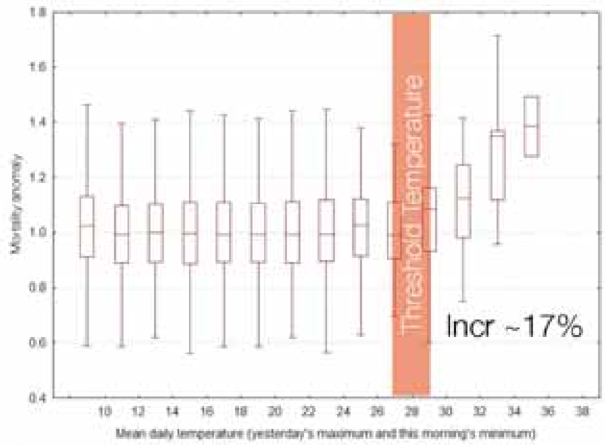

Melbourne - Heat Threshold for Excess Deaths in >64 y.o.

Nicholls, Skinner, Loughnan and Tapper, 2008

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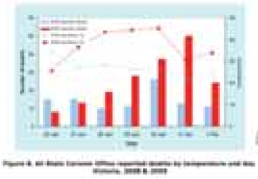
DHS Report Released April 6th, 2009

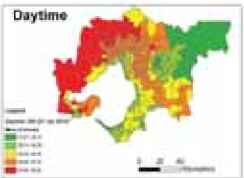
374 excess deaths Jan. 26 - Feb. 1 (62% jump over previous year)

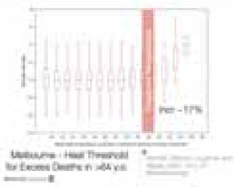
66% of excess deaths were in 75+ age group

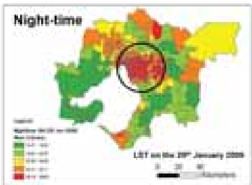


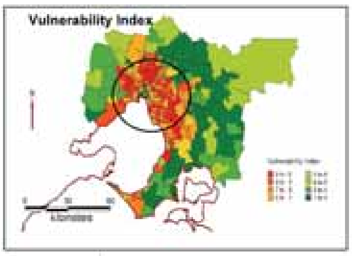
DHS 2009

The Age, April 6, 2009









Heat and Vulnerability

Loughnan, Nicholls and Tapper, 2009a

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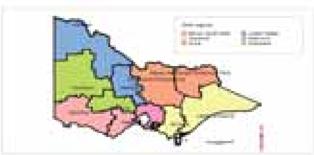
Heat thresholds for other Victorian centres

Threshold temperatures (°C) for rural Victorian centres. Numbers of episodes exceeding thresholds during the study period are listed in parentheses. The percentage increase in mortality on days exceeding the threshold is also shown for each threshold. (Loughnan, Nicholls and Tapper, 2009)

Major centre (SD)	Threshold temperature					
	Tmax		Tmin		MeanT	
Bendigo (Loddon)	40 (14)	8%	22 (18)	5%	32 (23)	18%
Wodonga (Hume)	40 (16)	20%	28 (4)	3%	30 (28)	None identified
Latrobe Valley (Gippsland)	36 (41)	10%	22 (8)	12%	30 (23)	18%
Horsham (Grampians)	38 (103)	10%	None identified	None identified	32 (15)	10%
Hamilton (Western District)	42 (6)	5%	24 (10)	7%	34 (2)	7%
Lakes Entrance (East Gippsland)	38 (21)	13%	23 (24)	7%	30 (10)	7%
Geelong (Barwon)	40 (19) 1 day lag	10%	20 (11)	4%	28 (39)	15%
Shepparton (Goulburn)	43 (3)	36%	26 (8)	15%	30 (23)	13%
Ballarat (Central highlands)	32 (13)	5%	18 (65)	10%	28 (16)	18%
Mildura (Mallee)	44 (7)	18%	27 (14)	10%	35 (20)	10%



Loughnan, Nicholls and Tapper, 2009b

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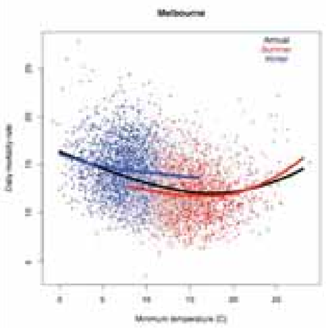

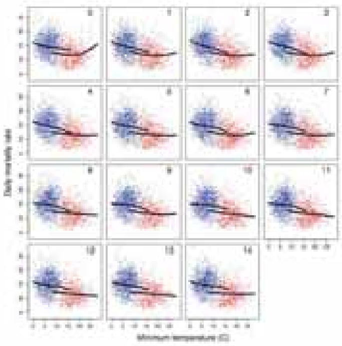

Seasonal and Synoptic Controls on Mortality in Melbourne

Nicholls, Loughnan and Tapper, 2010. Int J. of Health Geographics (in review)

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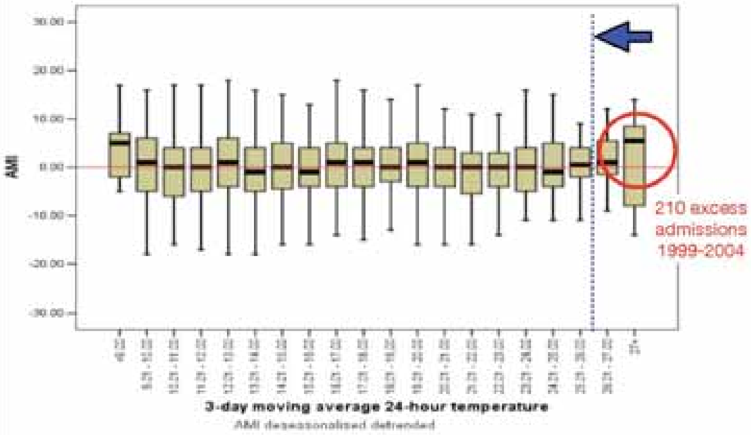

Melbourne Temperature and Excess AMI in >64 y.o.

Loughnan, Nicholls and Tapper, 2009c, Applied Geography

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The Health Costs of Extreme Temperatures

- For AMI health costs ONLY for Melbourne (i.e. not including mortality costs, other climate sensitive diseases or the costs to the economy of lost productivity)
- 210 excess admissions over period of 1999-2004 @ $8K/day for a average of 5 days = $8.4 million
- Projected dramatically increased costs of treating climate sensitive diseases over the next 25 years; e.g. Cardiovascular Disease 142%
- Combined effects of climate change, increased health care costs, increased urbanisation and aging population = $$$$

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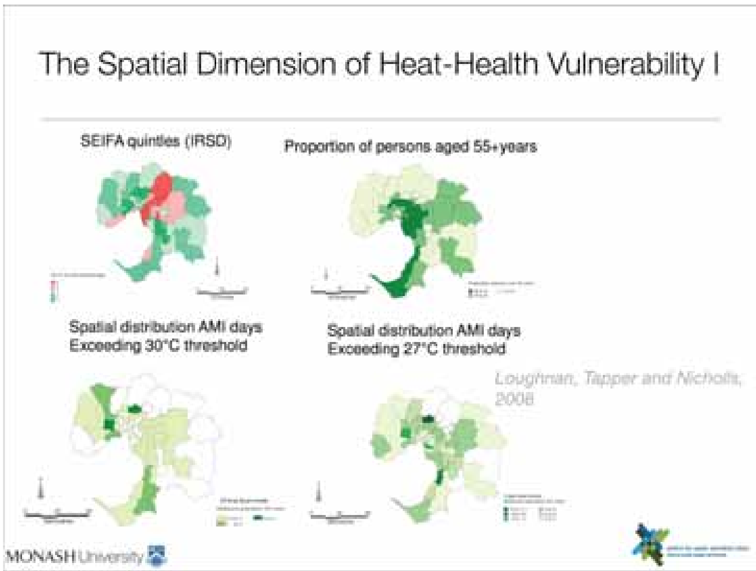

The Spatial Dimension of Heat-Health Vulnerability I
SEIFA quintiles (IRSD)
Proportion of persons aged 55+years
Spatial distribution AMI days
Exceeding 30°C threshold
Spatial distribution AMI days
Exceeding 27°C threshold
Loughnan, Tapper and Nicholls, 2008
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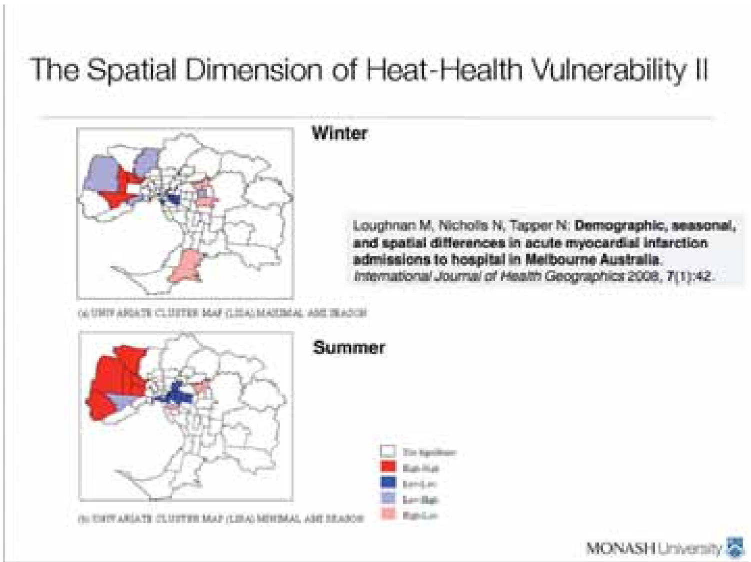
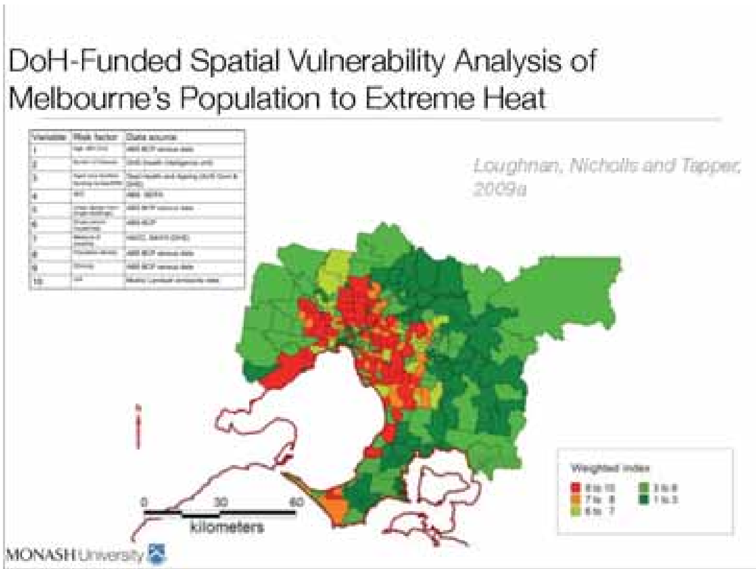
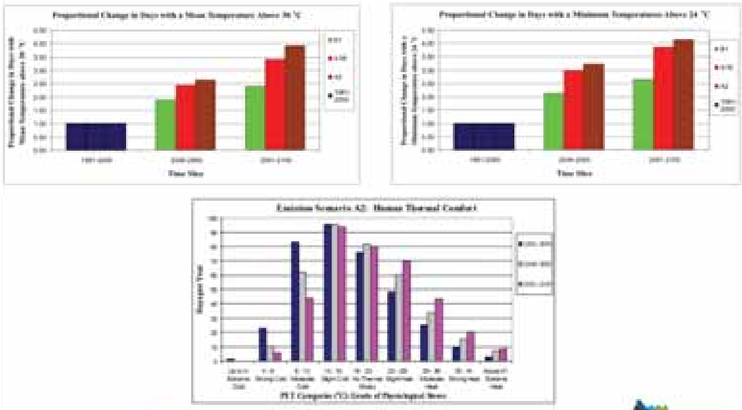


The Spatial Dimension of Heat-Health Vulnerability II
Winter
Loughnan M, Nicholls N, Tapper N: Demographic, seasonal, and spatial differences in acute myocardial infarction admissions to hospital in Melbourne Australia. International Journal of Health Geographics 2008, 7(1):42.
Summer
MONASH University



DoH-Funded Spatial Vulnerability Analysis of
Melbourne's Population to Extreme Heat
Loughnan, Nicholls and Tapper, 2009a
0 30 60
kilometers
Weighted index
MONASH University

Trends in Outdoor Thermal Comfort for Melbourne under Projected Climate Change



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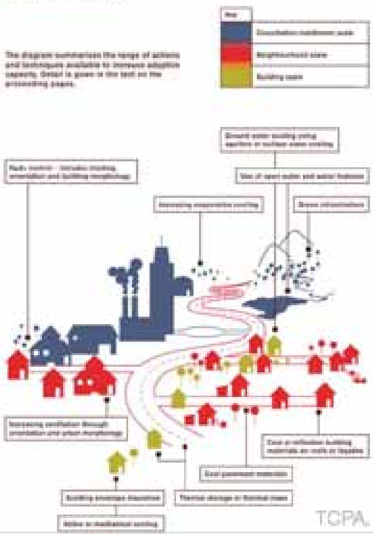
Joffe, et al. 2010, (in preparation)

Strategies for improving urban climate

- A range of strategies available including solar control, insulation, use of water in the environment, ventilation, etc
- I believe that the most effective way to improve the urban environment, for a range of benefits (improved human comfort, reduced fire danger and reduced water scarcity) is to reintroduce water into the urban landscape i.e. move towards ***Water Sensitive Cities***



TCPA, 2007

Cities as "Water Supply Catchments"

- A multi-million dollar, innovative and multidisciplinary initiative lead in Australia by Monash University
- Being supported by the National Water Commission, the Victorian State Government and industry
- Highly relevant nationally AND internationally - particularly for cities with issues around climate change and water scarcity

http://www.watersensitivecities.org.au/

To harness the potential of storm water to overcome water shortages, reduce urban heat island effects, and improve the landscape and liveability of Australian cities.

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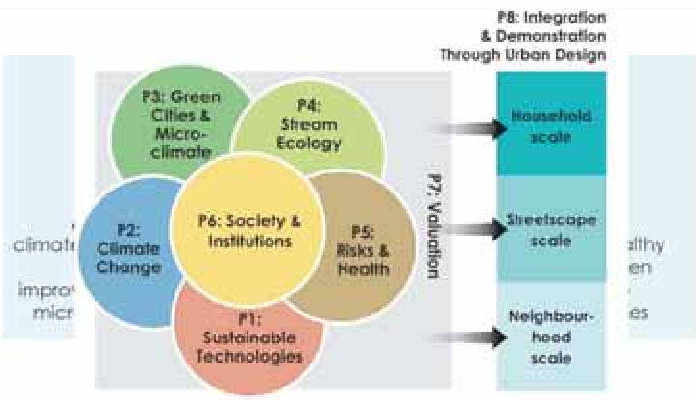

Cities as Water Supply Catchments Project ($15-20 m over 5 years beginning 2010)

Our research program aims to harness the potential of stormwater to overcome water shortages, reduce urban heat island effects, and improve the landscape and liveability of Australian cities.

Indicative Research Questions Relating to WSCs and Human Health

- By how much do we need to reduce urban temperatures to avoid excessive mortality under heat wave conditions?
- Can UHI mitigation strategies, including re-incorporating water into the urban environment, provide "headroom" for some of the regional warming that is now unavoidable?
- What are the attributes of a WSC that improve human thermal comfort?
- Can we manipulate urban climates to maximise winter and reduce summertime minimum temperatures?
- What are the opportunities for immediately 'pre-heatwave' landscape treatment to reduce thermal stress?

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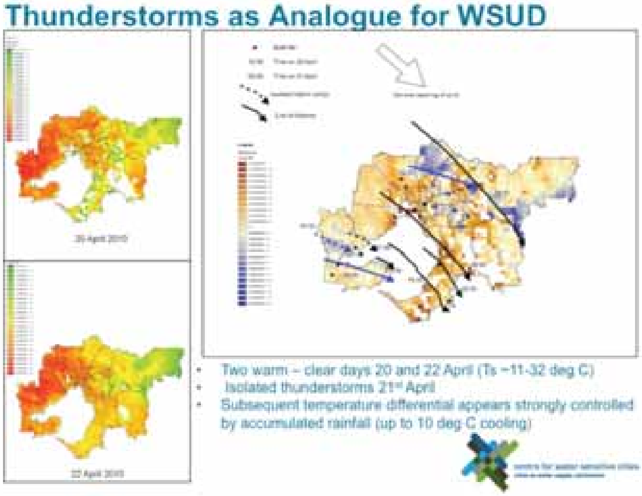
Thunderstorms as Analogue for WSUD



- Two warm – clear days 20 and 22 April (Ts ~11-32 deg C)
- Isolated thunderstorms 21st April
- Subsequent temperature differential appears strongly controlled by accumulated rainfall (up to 10 deg C cooling)

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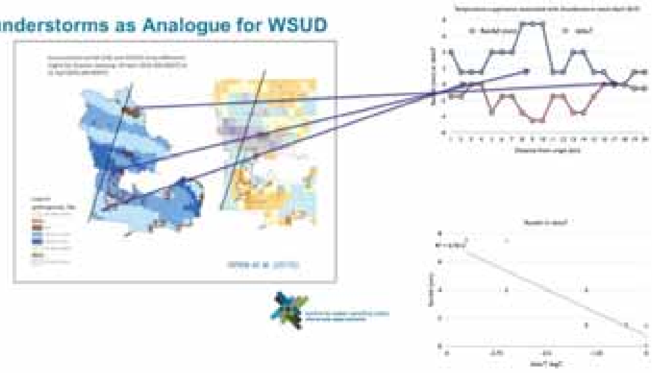
Water sensitive cities – keeping water in the urban landscape to achieve cooling II

Thunderstorms as Analogue for WSUD



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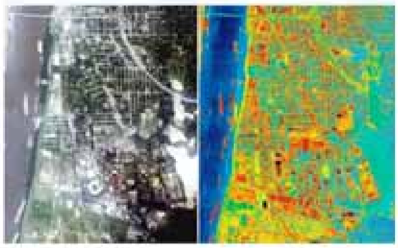
Concluding Comments

- Climate change poses particular problems in urban areas - probably no more so than in the world's Mediterranean regions
- It is critical to find innovative, cost effective and environmentally friendly approaches to mitigate the impacts of climate change in urban areas, particularly to solve issues around *human health and water scarcity.*
- We are working towards a solution for these problems. Inevitably some of these approaches will involve innovative use of urban water, in particular *wastewater reuse and storm water harvesting (and by implication dramatic increases in green infrastructure), water sources that are currently wasted*

Urban Heat Island



Recessed landscape for storm water capture and storage

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Coutts A.M., Beringer J., and N. Tapper N, 2010 "Changing urban climate and CO2 emissions: implications for the development of policies for sustainable cities." *Urban Policy and Research* (First Published online: 06 January 2010 . DOI: 10.1080/08111140903437716.)

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WATERING ADELAIDE'S TREES IN TIMES OF DROUGHT: WHY, HOW, AND IS IT WORTH IT?

Chris Daniels[1], Philip Roetman, Keith Smith, Sheryn Pitman, Beth Curran, Darren Ray, Pam Gurner-Hall, John Zwar, Christine Goodwin, Graeme Hopkins, David Lawry, Tim Johnson, Martin Ely and Trevor Nottle.

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This paper is an abstract of several sections of the recently published book:
Daniels C.B. (ed)(2010) Adelaide: Water of a City. Wakefield Press, Adelaide.
All the affiliations and addresses of the authors can be found in the front of the book

More information about this book is available at:
http://www.unisa.edu.au/barbarahardy/books/water.asp

Introduction

Adelaide is a forest city, planted with a rich mixture of local and exotic trees, plants, shrubs and ground covers (the exotics being both Australian and non-Australian). This green infrastructure offers a huge range of benefits to a city, ranging from social and aesthetic to promoting biodiversity and even influencing the climate. The recent drought with its concomitant water restrictions and the spectre of climate change has refocussed interest in this green infrastructure. In this paper we consider:

1. Adelaide's climate
2. Adelaide's green infrastructure
3. What is happening in Adelaide to save the green infrastructure?

Part 1: Adelaide's climate

Adelaide is often referred to as having a Mediterranean climate, with dry, warm to hot summers and temperate winters, and a distinct rainfall maximum during the winter months. Spring and autumn rains can be frequent but do not contribute as much as winter rainfall. Adelaide receives about 150 mm of rain January –June, about 300 mm July–September and about 100mm October-December.

Summer

During the summer months, maximum solar heating occurs in the tropics south of the Equator. The relatively cool ocean waters of the Great Australian Bight and the Western Pacific are preferred locations for the large high pressure cells making up the sub-tropical ridge. Adelaide's day-to-day weather during this season is largely determined by a High Pressure centred in the Great Australian Bight. Days are generally fine and winds are generally light. The southerly onshore stream keeps relative humidity in the mid-range and temperatures in the mid-twenties.

However, when the Western Pacific high pressure centre anchors in the Tasman Sea and extends a ridge of subsiding air over Queensland and New South Wales, a hot, dry northerly stream prevails over Adelaide. This is a potential weather pattern for heatwaves, with daily maximum temperatures in the mid to high 30s. In extreme events, several days with temperatures exceeding 40ºC may occur. The sequence is broken by a front or trough moving in from the west. Brief thunderstorms and showers may occur with summertime fronts but most often there is no cloud or precipitation. Rather, the frontal passage brings a sharp wind shift, the much awaited 'cool change', and a return to a southerly stream as the high pressure rebuilds in the Bight. Significant rainfalls in summer are usually infrequent short-lived severe thunderstorm events.

Winter
In winter the belt of maximum global heating lies in the Northern Hemisphere, shifting the southern Hadley Cell northwards. The mean position of the subtropical ridge now lies to the north of Adelaide, and the prevailing airstream is from the west. Travelling frontal systems in the stream are responsible for the generally reliable rainfall in these months. The Mount Lofty Ranges, running roughly perpendicular to the air stream, force the air to rise, enhancing the precipitation processes and effectively wringing extra rainfall from fronts and moist air-streams as they move over Adelaide.

Many of the more significant winter rainfall events occur when moist tropical air is drawn into a weather system such as a northwest cloudband or a cut-off depression. The air originates over warm oceans and holds much more water vapour that does the air originating south of Australia. Cut-off low pressure systems entrain moisture from the Coral and/or Tasman Sea and have the potential to produce flooding. A widespread rainband, as well as convective clouds including thunderstorms with heavy downpours, can occur. These slow moving systems can produce rain events lasting 12 to 24 hours. While the systems are slow moving the associated winds can be fresh to strong and recirculate the moist air over Adelaide, giving successive rainfall bursts leading to major flooding.

Widespread droughts brought on by failed winter and spring rains across southern and eastern Australia are often attributed to El Nino events. However, across southern South Australia, dry winters also occur when the subtropical ridge is stronger than usual, with the westerly wind belt then favouring more southerly latitudes. Hence, the subtropical ridge and associated blocking highs in the Australian region play a major role in steering frontal systems further south of South Australia than usual.

In winter months daily temperatures are in the mid teens, and overnight temperatures average below 10 ºC. Average maximum temperatures are typically warmer and winter minimums colder in drought years when there is less water vapour in the lower atmosphere.

Autumn and spring
During autumn and spring Adelaide’s mean daily temperatures change rapidly as the belt of maximum global heating follows the Sun across the Equator. Autumn brings balmy days and light winds under the influence of the subtropical ridge. History shows that by late autumn Adelaide has normally received its first good rains for the year. These may be the signal that the winter westerlies are settling in over southern South Australia, but occasionally the early rains prove to be ‘false starts’. In these years the subtropical ridge delays its northward movement, preventing the onset of the westerlies and associated travelling weather systems till well into winter, if at all.

In spring, the Australian land mass warms rapidly as the zone of maximum global heating again moves into the southern hemisphere. This produces a strong temperature gradient between the land and the cool Southern Ocean, setting up conditions for the ‘continental sea-breeze’ effect. This is the season of maximum windiness in Adelaide as fresh and gusty south-westerlies, most prevalent during the afternoon, move in from the Southern Ocean. As this occurs, the mean position of the belt of maximum westerly winds circling the globe retracts to the south and the average monthly rainfall and rain days per month decrease.

Rainfall
Adelaide’s mean annual rainfall is around 550 mm in the city, but there is a gradual increase across the plains from around 400 mm on Lefevre Peninsula, to over 600 mm in the foothills. This gradient is accentuated on the western slopes of the Mount Lofty Ranges where at higher elevations such as Uraidla and Mount Lofty the mean annual rainfall exceeds 1100 mm, and then decreases sharply to the east. Moving north across the city, annual rainfall totals decrease from 634 mm at Happy Valley to around 430 mm at Elizabeth and then 500 mm at Gawler on the lower slopes of the Ranges. Adelaide’s (recorded) annual rainfall has varied from a low of 257.8 mm in 1967 to a high of 883.2 mm in 1992.

Climate variability, climate trends and climate change

Adelaide's climate has a high natural variability, characteristic of much of Australia, and clearly evident on all timescales from inter-annual, decadal to centuries and longer. Superimposed on the natural climate variability, there is now clear evidence of recent global warming at rates outside the experience of modern society. Recent climate trends observed in our region include:

1. An increase of 0.9ºC in mean temperature across Australia from 1910 to 2006 with most of the warming occurring since 1950, at a rate of 0.16ºC per decade. With this warming there has been an increase in the number of hot days (> 35ºC) and hot nights (> 20ºC) and a decrease in the number of cold days (<15 ºC) and cold nights (<5 ºC) per year.
2. Annual rainfall in Adelaide shows inter-annual and multi-decadal variability but there is a clear peak during the 1970's. On a seasonal basis a recent decline in autumn rainfall is evident across south-eastern South Australia including Adelaide.
3. Droughts are peppered throughout the record, but the average temperature in recent drought years has been warmer than in droughts of the early 20th century. This increases heat stress and potential evaporation which can exceed rainfall over much of the year in many locations, thereby exacerbating the severity of the rainfall deficiencies. The timing of rainfall, e.g. a 'false autumn break' can also play a critical role in determining water stress.

Future climate projections for southern Australia

While there is confidence that increasing atmospheric greenhouse gas concentrations will result in further warming in our region over the next century, for other climate variables such as rainfall and extreme events, the link to global warming is far more complex. It is not feasible to simply extrapolate recent trends. To a large extent, changes in these elements will be driven by changes in the local features of the global circulation. Using the IPCC, in its 4th Assessment (2007), drew the following conclusions:

1. Most models project global warming over the next two decades at around 0.2ºC per decade. Continued greenhouse gas emissions at, or above, the current rates would cause further warming and induce many changes in the global climate system during the 21st century that would very likely be larger than those observed over the past 100 years.
2. Sea level pressure is projected to increase in the subtropics and mid-latitudes (Adelaide latitudes) and decrease over high latitudes due to a poleward expansion of the Hadley Circulation and a poleward shift in storm tracks.
3. Globally averaged mean atmospheric water vapour, evaporation and precipitation are projected to increase (i.e. intensification of the hydrological cycle) but precipitation is expected to decrease in the subtropics and mid-latitudes. Even where mean precipitation decreases, precipitation intensity (mm/unit time) in specific events is projected to increase, but the duration between such events will also increase.

The best estimate for annual warming in the Adelaide region to 2030, relative to the 1990 mean temperature is 0.9ºC, with slightly less warming in winter. The number of days with temperatures over 35ºC is projected to increase from 17 currently to 23 and there is expected to be a small increase (~2%) in annual potential evaporation. The best estimates suggest continued increases in mean temperature and potential evaporation throughout the century. The projected change in annual rainfall in 2030 is an overall decline of 4%, with the most pronounced declines, of 8% and 6% in the wetter seasons of spring and winter. The projections for 2030 also show a small decline (< 1%) in relative humidity and very small increase of +0.2% in solar radiation.

With less rain, the vegetation and soils around Adelaide and the Mt Lofty Ranges will dry. In combination with higher temperatures, the risk of bushfires intensifies. Heatwaves are the most dangerous culprits in this relationship. The 15-day March 2008 heatwave in Adelaide was, on the basis of the 20th century temperature record, a staggering 1 in 3,000 year event. Yet under a mid-range projection of global warming (should no action be taken to quickly curtail carbon emissions), such an event would be an expected part of an average summer. Such heatwaves and regular intensive fires also causes great stress to most species, leading to higher mortality, failed reproduction, and reduced body condition. These synergies, between water availability, hotter temperatures and changed fire regimes, are some of the primary reasons why unrestrained climate change is anticipated to lead to the extinction of an appallingly large fraction of our biodiversity.

Part 2: Adelaide's green infrastructure

Adelaide's urban forest

The term "urban forest" is often used to refer to the dense cover of vegetation which can be seen over much of Metropolitan Adelaide from vantage points such as the Mount Lofty Ranges. Girardet (2003) commented:

> *Adelaide is fortunate in having a significant cover of urban vegetation and it has been noted that it looks like a city in a forest from the air, having in excess of 20 million trees growing in the metropolitan area.*

Historically, 21 native vegetation associations occurred in and around the Adelaide area, ranging from open forests and woodlands along South Road at Black Forest to shrublands at Merino. Today only 2.7% of the original vegetation remains, with most of the remainder being planted vegetation in parks and gardens. The dominant land cover types for metropolitan Adelaide and a description of each are as follows:

Urban forests are where trees up to 30 metres form the tallest stratum and foliage cover as projected on the ground is approximately 30% or greater. Urban forests are usually limited to stands of mature, dense vegetation (both native and exotic), and include mangrove areas around the Barker Inlet, trees in mature urban gardens, and suburban areas with older trees and street tree plantations, especially around the foothills.

Urban woodlands occur where trees or large shrubs form the tallest stratum and foliage cover is between 20% and 30%. In urban areas, this land cover type is mainly confined to Metropolitan Open Space reserves, gully escarpments and older suburbs around the foothills. Urban woodlands also include areas of dense coastal shrublands and vegetation around reservoirs.

Urban open woodlands occur over most residential areas in Metropolitan Adelaide, where trees or large shrubs form the tallest stratum and foliage cover is up to 20% of the area. This land cover type comprises predominantly urban vegetation, including tree and shrub plantings dominated by mixed woodland formations and introduced exotic vegetation. Urban open woodlands often occur over grasslands, parklands or pasture. This category also includes sparse open woodlands over modified pasture in rural areas as well as recent vineyard and orchard plantings.

Urban grasslands include irrigated and non-irrigated turf and open grassland areas such as reserves, golf courses and institutional and industrial lands in urban areas, as well as irrigated and non-irrigated crop and pastures in horticulture and rural zones. It also includes disturbed sites, such as new housing development sites, often characterised by weedy cover. Urban grassland areas vary from grass cover up to 100% of the ground (irrigated grasslands) to areas with less than 10% cover (weedy grasslands).

In 1990 urban woodlands and forests covered approximately 31.4% of metropolitan Adelaide, comprising 6.1% urban forests, 11.6% urban woodlands and 13.6% urban open woodlands. Urban grasslands covered approximately 15.6% of the metropolitan area. By 2000, urban woodlands and forests covered approximately 36.4% of metropolitan Adelaide. Urban forests covered approximately 5.7%; urban woodlands 14.7%, urban open woodlands 16.0%, while urban grassland areas cover 14.8% of the metropolitan area. The total vegetation land cover for Adelaide increased approximately from 47.0% to 51.0% of the total area in 2000. These increases are significant, having occurred over a relatively short time span, pre drought and water restrictions. Trees and vegetation growing in gardens and on private lands (approximately 90%) comprise the majority of Adelaide's urban vegetation cover.

The value of the urban forest

Green infrastructure has a vital part to play in curbing the effects of drought, heat and climate change. The urban forest is helpful in ameliorating climatic extremes, but it is also vulnerable to it too. Climatic changes, such as increased heat and reduced rainfall, will radically change the landscape and ecology of Adelaide and the quality of life for its citizens.

Street trees are beneficial in reducing the heat island effect through lowering ambient air temperatures and interrupting glare and reflection from surrounding hard surfaces. Trees also act as efficient filters of airborne particles because of their large size, high surface to volume ratio of foliage, frequently hairy or rough leaf and bark surfaces, and when planted in rows or as loose plantations they intercept and retain atmospheric particles through the wind current as it passes between them or is pushed up and over the trees. Moreover, recent Indian research suggests that a thin screen of trees is more effective at removing and retaining airborne impurities and dust particles than a densely planted plantation which creates more air turbulence and subsequent relocation of the particles. In addition, smaller compound leaves are generally more efficient particle collectors than larger leaves and that different shaped leaves have different abilities to capture dust particles. Street trees also provide an additional range of benefits and services, including:

1. Improved visual amenity, human health and increase in real estate values.
2. Provision of screening for increased privacy.
3. Reduced heating and cooling costs (through shading and windbreak effects).
4. Increased personal comfort through shade and amenity.
5. Increased safety through increased passive surveillance, community socialisation and networking.
6. Trees planted as personal or community memorials have significant historic or heritage value.
7. Provision of leaf mulch and compost materials that can be used for soil enrichment and maintenance.
8. Reduction or eradication of glare and reflection of heat and light, moderating climate both locally and globally.
9. Enhancing views, screening undesired views and complementing or softening architecture.
10. Improving air quality by fixing carbon dioxide and carbon monoxide, producing oxygen and filtering dust.
11. Provision of habitat for wildlife and provision of associated educational opportunities.
12. Reduction of water run-off, helping to prevent erosion, dryland salinity and related groundwater issues.
13. Provision of employment (equipment manufacturers, retailers, educators, researchers, arborists, mechanics and horticulturalists).

With the exception of some older heritage streetscapes, which consist of large numbers of similar species of mature trees, economic values can be difficult to ascribe to urban vegetation. This is especially true for vegetation cover which contains mixed species, types and plant ages. As a consequence, urban vegetation may be managed in a piecemeal way with little regard for the economics and practicalities of eventual replacement until significant numbers of trees fail or die.

At the 2002 TREENET Conference Killicoat and colleagues calculated the gross annual benefit of a typical Adelaide street tree (a four year old Jacaranda) at $171 per tree. T his benefit consisted of energy savings due to reduced air conditioning costs ($64), air quality improvements (CO_2 reduced power output $1, and air pollution treatment $34.50), stormwater treatment ($6.50), aesthetics and other benefits ($65.00).

Drought conditions and declining water resources led to the introduction of Level 2 water restrictions in Adelaide in 2006, and were increased to the more stringent Level 3 restrictions in 2007. These restrictions were effective in helping to reduce Adelaide's water consumption, which fell from 216 GL in 2005 to 140 GL in 2007. However, the effect on the urban vegetation was very significant and is ongoing. The lack of water has already resulted in the death of grasses, shrubs and many of our older trees. As the drought continues and the soil dries out at deeper levels, around the tree roots, our older and larger trees are likely to continue to show effects of these impacts and continue to deteriorate and die over many years. Serious social, economic and ecological impacts are likely to follow the deterioration of urban forest cover, in terms of stormwater management, temperature modification associated with the loss of shade, air quality and community life in the region.

Although urban trees have significant additional values which are not considered in the economic assessment by Killicoat and colleagues (2002), they suggested the following conservative but alarming value of tree loss due to climate change and drought can be calculated. For 10,000 trees lost in the urban landscape to the effects of climate change and drought, the annual loss of environmental services (at 2002 values) will be approximately $1,700,000 per year, every year. The figure of 10,000 trees is conservative (0.5% of Adelaide's tree population) if we consider that the loss of trees associated with drought and climate change is not limited to just street trees but also includes trees on parks, reserves and home gardens. Although it is likely that Councils will replace street tree losses over time, the same cannot be assumed for private gardens. Hence a more reasonable estimate is that the drought of 2008 resulted in the loss of 100,000 trees across Adelaide, then the annual cost of the loss of these environmental services to the community will be $17,000,000 per annum.

Adelaide's Level 3 water restrictions may seem moderate compared to those enforced in other Australian cities such as Brisbane, which has reached Level 6 restrictions. However, Brisbane's climate is very different to that of Adelaide. For example, Brisbane's average annual rainfall is nearly double the amount that Adelaide receives, and it experiences hot, wet summers. In comparison, Adelaide summers are much drier and plants suffer from increasing water stress during this period. Due to its climate, Adelaide cannot afford to implement higher, tighter levels of water restrictions.

Part 3: What is happening in Adelaide to save the green infrastructure?

Watering practices in open space

During the early years of the twentieth century, Adelaide parks were watered by impact sprinklers, hoses with bayonet fittings, travelling tractors, fluming and coupling pipes, rows of sprinklers shifted regularly by caretakers or gardeners dedicated to particular ovals or reserves, with equipment often stored in site huts. Some areas were very green and others not irrigated at all. During the 1950s, 60s and 70s many of the councils with larger geographical areas employed large numbers of field staff to look after the many new ovals and reserves. During the 1980s there was a change in community perceptions about green space and expectations became greater. Prior to the 80s having open space was sufficient, but suddenly it all had to be green. There was little science involved with irrigation, although some councils chose not to water if it was raining.

Adelaide was watered from various sources. Water for irrigation was either from the mains system (River Murray and local catchments), pumped from bores or pumped from rivers. Small rivers and creeks were also important water sources. From the 1980s automatic pop-up sprinkler systems replaced manual systems, with several councils reporting that, while making life easier, these new automatic systems tended to result in over-watering. During the 1980s and 90s several councils connected their irrigated spaces to the externally controlled Micromet pop-up sprinkler irrigation system, designed to match irrigation patterns with weather patterns. Also from the late 1980s, sub-surface drip irrigation systems were installed in most council areas. New technologies developed quickly throughout the 1990s and automatic irrigation systems became more efficient and less wasteful. During the 90s changes were increasingly implemented. These were variously due to the cost of water, the cost of staff leading to staff reductions and to the fact that staffers were better educated and knowledgeable about the water needs of their open spaces.

Since around the year 2000, change has occurred quickly. All councils have undergone rapid developments in areas such as water harvesting and recycling, reductions in water use, improved intelligent irrigation systems, system audits, smart scheduling, moisture sensors and probes, rain sensors, subsurface irrigation, better maintenance practices, monitoring, analysis of soils and site conditions before irrigation systems are installed, and introduction of the IPOS (Irrigated Public Open Space) Code of Practice (an initiative of the SA Government's Waterproofing Adelaide Strategy, the IPOS Code of Practice encourages irrigation efficiency by addressing turf and irrigation management through sound planning, programming and monitoring). Now councils are growing more creative and opportunistic in their searches for alternative water supplies. Tea Tree Gully uses recycled water collected in and taken from an old clay and mineral quarry for irrigation, water trucks and street sweepers. The River Torrens is still used to water the Linear Park and two district sports fields direct irrigation water into sub-surface drainage tanks which is mixed with mains water, treated, and pumped back up and reused. Aquifer Storage and Recharge (ASR) is increasingly being investigated and utilised. Salisbury Council has developed alternative water supplies, an example being the Mawson Lakes recycled water system. The extensive construction and use of wetlands for harvesting has enabled the Salisbury Council to keep water costs under control while effectively managing their significant flooding and stormwater issues.

Plant selections: deciduous (introduced) or evergreen (indigenous)
Adelaide has extensive plantings of exotic and deciduous trees in its open space, streets and private gardens. There is an emphasis on native plantings in public lands and open space reserves. In Metropolitan Adelaide, a broad range of Australian species were planted as street trees throughout the 1960s to the 1980s, including *Acacia, Eucalyptus, Melaleuca and Lophostemon,* especially in the newer and rapidly expanding suburbs to the north and south of the city. However, Adelaide also has large numbers of exotic deciduous street trees including plane trees *(Platanus sp.)* and ornamental pears *(Pyrus sp.)*, particularly in older central suburbs and gardens. Recently there has been considerable discussion about the need to plant local indigenous species as it is assumed that these trees will perform better under local conditions. However, this view fails to consider the radical changes urbanisation has had on soils, hydrology and the local micro-climate conditions. Indeed, many Australian species, such as the larger eucalypts, struggle with these altered conditions and can have significantly increased maintenance costs associated with road and infrastructure damage as they mature. Also the argument against deciduous species based on leaf litter is flawed as all species, including Australian trees, create leaf litter and that unlike deciduous species, evergreen trees extract relatively little nutrient from their leaves before shedding. These leaves also fall most often during summer when water levels in creeks and watercourses are low and pollution levels will be most concentrated. Deciduous species also provide structural diversity in the landscape and a range of services including reduced cooling costs in summer when they are in leaf and conversely, reduced heating costs in winter when they have dropped their leaves.

However, in contrast to street tree plantings, landscaping in public open space is now carried out predominantly with drought tolerant plant species, particularly including more use of local indigenous species. Such new plantings often receive irrigation only for the first two years for establishment purposes. The Windsor Street Linear Trail is a particularly successful example of replacing introduced deciduous trees with indigenous species. The re-landscaping of this street and verge involved the removal of mature oaks and elms to make way for local plants. The biodiversity and education outcomes of the Windsor Street landscape are considered by Unley Council to be valuable, while the site is also an important seed bank used for propagation of threatened plants.

Plant selections: choosing waterwise plants
With recent drought conditions, plant selection for waterwise plants has become of utmost importance, whether they be native, horticultural or ornamental. We need to select plants that grow well on the natural rainfall, with minimal supplementary water in dry periods. There is a vast selection of plants which do just this including groundcovers, grasses, low and medium shrubs and trees. These plants usually originate locally or from places similar in climate and soils to our own. The important proviso here is that we select plants that are not invasive and will not become weedy, as we can easily create other more difficult problems if we choose invasive plants.

To select plants that are water efficient, it is useful to look at the foliage. Pale coloured foliage will reflect heat and light and therefore require less water. Small, waxy, hairy leaves will lose less water than broad flat leaves. Needle-like leaves are also water efficient, and succulent leaves store water for dry times.

The second principle involves water conservation. This means using practical measures to ensure that plants and gardens make the best use of available water. There are a variety of ways to achieve this. First of all, many plants become established more quickly if planted in late autumn or early winter rather than spring or summer. The ideal time is after the opening rains for the season (April, see above). Most plants will benefit from becoming established over winter so that they can be ready for the long periods of dry and hot weather. This greatly reduces the amount of water they will need through spring and summer. For the first or second summer some plants will need supplementary water, but early planting reduces this requirement.

Good placement of plants can make a difference. Grouping them according to their water and sunlight or shade needs, will make the best use of the naturally dry and damp areas in the home garden. Adding compost to the soil improves water retention, and it is important to mulch well and maintain the mulch cover. Coarse organic mulch is best as it allows rain to penetrate the soil, and also provides nutrients to the plant. It is wise to apply mulch when the soil is already damp. Efficient under-mulch drip irrigation is usually the most effective way to water plants should they need a drink, however if restrictions preclude dripper systems, a bucket or watering can be used.

Plants that have been planted at the right time of year in appropriate positions and are well mulched should only need occasional watering, even in dry periods. Water must reach the root zones of plants to direct any supplementary water carefully. It is usually most efficient to apply water in the early morning rather than in the heat of day.

There are many plants that will grow well in South Australian gardens and not use much more water than rainfall provides. Some of the plants that have been popular during the past century have required significant amounts of supplementary water. However, in this period of freshwater uncertainty, there is no reason why we cannot still achieve beautiful gardens. It is a matter of working in harmony with the climate and landscape rather than against it.

Plant selections: to lawn or not to lawn

There are many sound arguments for keeping a patch of lawn for the kids to play on. Lawn can assist the cooling of a house if placed on a north/western aspect in Adelaide and shaded in turn with a broad canopy tree, even better, if watered by grey water through a below ground drip irrigation system or recycled grey/black water from an Enviro-cycle system or similar. Lawn can lower reflected heat, and allow for water to penetrate and limit runoff into the storm water system. These are all good reasons to consider keeping a small useable amount of lawn, however, lawns in front gardens particularly with a southern aspect have limited value other than for aesthetic purposes. If planting lawn, the type of lawn selected is very important. Turf varieties are often more reliant on water than 'running' type lawns such as Couch or Kikuyu (varieties). These lawn varieties will often brown off in the summer and return to a lush green once the rains come again. While being able to water a lawn with recycled water may be good justification to enable one to be grown, consideration should be given as to what other 'useful' plants may be grown in its place (for habitat or production). Consideration should also be given to a selection of water efficient native grasses that have been trialled and proved to perform well as lawns, although these usually prefer not to be cut as short as traditional lawns. The maximum size lawn allowed in some towns in northern South Australia is 100 square metres.

Garden design

We are now considering the garden from a new perspective. Gardens must now provide habitat for people, as well as animals and birds. This means that the garden must "perform". Shade, shelter, privacy, protection, and by mindful plant selection, the resulting habitat and hence by default, biodiversity conservation, is the new direction for garden creation in our dry state. This garden will look good but is defined by a more layered measure, rather than a strict criterion of what currently defines a "good" garden. Rather than designing gardens driven from an aesthetic approach only, designing for a habitat of a particular species or number of species of birds and animals, allows for a substantial change in the choice of planting. Also consideration to allocated space to accommodate our new (non human) city residents translates to different approaches to spatial design. Plants need to be grouped together to accommodate protection and cover for small birds escaping from predators. Flowering plants are selected to perform throughout various seasons to both attract and support the chosen species. Consideration to available resource is a natural follow on from this as the garden supports the habitat, (water use being the main resource consideration).

Garden culture is also demonstrated in many different ways depending on cultural traditions. Fruiting trees and shrubs under planted with vegetables and herbs in front gardens abound in the Stepney, Campbelltown and Prospect areas of Adelaide where there are large Italian and Greek communities. These gardens are testament to the attractiveness as well as productiveness and wise use of water resource which differs substantially from the aesthetic approach of our predominately British heritage. The creation of food gardens within our home garden spaces is currently returning full circle. Up until recently the home vegetable garden was a typical feature of most residential gardens. The 1980s perceived era of prosperity put a temporary end to that as people thought that the hassle of planting a garden and maintaining it was an unnecessary drain on their constantly dwindling time constraint. However, with rising prices for fruits and vegetables we are seeing an advance in home grown food production. This has come at a time of increased pressure on our shrinking water supply. It is a situation which demands an immediate shift in our approach to water harvesting, storage, and water recycling within the boundaries of our own home gardens.

Green roofs and living walls
Green or vegetated roofs and walls provide many environmental benefits, including stormwater and water quality management, increased biodiversity, improved air quality, insulation to buildings and reduced air temperature. They form an integral layer in city-wide green infrastructure. In particular, bushtops, where a local ecosystem is created or re-interpreted to provide habitats for endemic species, provide further opportunities for biodiversity. A habitat template approach can be used to analyse the natural habitats of target species, and to then create a new urban habitat template to mimic these habitats on the rooftop. Plants need to be selected so that they match the environmental conditions of the built environment, which in most situations is relatively harsh. The bushtops do not need to be connected, but if located on a series of isolated building roofs they form stepping stone habitats, which can be integrated with adjacent habitat corridors.

Green roofs are beneficial for wildlife, people and help manage water runoff. Researchers in Europe have found that the deeper the substrate of a green roof is, the greater the vegetation biodiversity possible, and this also applies to the animal biodiversity. The main animal groups found on green roofs have been insects, spiders, birds, and lizards. Green roofs also play an important role in providing sufficient oxygen for humans, within an otherwise oxygen depleted urban environment. For instance, it has been calculated that $1.5m^2$ of uncut grass produces enough oxygen per year to supply one human with their yearly oxygen intake requirement. Green roofs are also able to reduce the amount of water available for runoff by using their absorption and evaporative ability. The water is used to sustain life on the green roof, and can be stored for a period of time before a delayed release to the existing stormwater drainage system.

Living walls provide a physical link between the ground plane of vegetation and their habitats with the rooftops of buildings, where green roofs and bushtops provide another layer of green infrastructure. Living walls consist of suitable plants growing in the ground and trained up trellises or other wire structures, or modular panels with plants growing in a lightweight medium held in a sturdy framework. Water is efficiently supplied to these plants via low volume drippers. The lush growth provides habitat to lizards, insects and birds, and allows their movement up to the rooftops. It has been shown in Europe that small lizards will climb to at least four stories to find a suitable habitat.

Water sensitive urban design (WSUD)
Water sensitive urban design (WSUD) is an integrated approach linking engineering and environmental principles that can help us achieve “green streets” in times of water restrictions. Stormwater runoff that usually flows down our drains and out to sea, can be harvested to irrigate street trees and other landscaping. At the same time, runoff can be filtered and cleaned of pollutants before returning it to aquatic ecosystems. Increasingly, the theory of WSUD is being adopted in Australian cities and can be defined as:

> *The integration of urban planning with the management, protection and conservation of the urban water cycle that ensures urban water management is sensitive to natural hydrological and ecological systems.*

The aims of WSUD are to:

1. Maximise the potential for water reuse.
2. Reduce pollution associated with stormwater outfall to the marine environment.
3. Reduce peak water flows and flood risk.
4. Provide water for the environment.
5. Provide aesthetic and social improvements.

In recent years, WSUD treatments have evolved from large scale “end of pipe” solutions, such as constructed wetlands, to smaller scale applications which can treat runoff from local catchments “at source”, and which can be integrated into the design of urban streets and public spaces. These smaller scale applications deliver a range of benefits. As well as protecting downstream waters through pollutant removal and retarding of stormwater flows, they can also harvest runoff for local landscape reuse. This can reduce the use of mains water for irrigation, creating “self watering” landscape features, and enabling the greening of streets in times of water restrictions. They also help increase awareness of the connections between human activities and the water cycle, by making the processes more visible.

Streetscape-scale WSUD applications can take a number of forms, however the most popular are bioretention systems (also known as raingardens) which can be scaled to confined spaces, and adapted to a range of urban situations. Bioretention systems filter stormwater runoff through a vegetated soil media layer. The filtered water is then collected via perforated pipes and discharged back into the stormwater system, or stored for reuse. Temporary ponding above the soil media, in an “extended detention zone”, provides additional treatment by sedimentation. Bioretention systems, however, are not intended to function by infiltration. Treated water is returned to the stormwater system, rather than into the surrounding soil and groundwater. Bioretention systems also typically include a high flow by-pass, to capture the most contaminated “first flush” during rain events, while diverting excess flows to the main stormwater system.

Vegetation growing in the filter media enhances the function of the raingarden in a number of ways. Plant roots help remove pollutants through a combination of physical, chemical and biological processes. They also prevent erosion of the filter media, and maintain its porosity through continuous root growth. An appropriate filter media is therefore required, which balances the need for efficient flow through the soil profile, with the need to retain sufficient water in the soil to sustain plant growth. Sandy loams are typically most suitable, however a specialised soil media, with a number of layers, can be designed to suit local conditions. A wide range of plants can be used in bioretention systems, however species which tolerate periods of drought and inundation are preferred to the more aquatic species, as the former act as indicators of system failure due to clogging of the soil media.

Bioretention systems can also take the form of bioretention basins or linear swales. Bioretention tree pits are a recent innovation, allowing the incorporation of stormwater management into confined urban street spaces. Bioretention systems can be integrated into the design of new streets, or “retrofitted” into existing streetscapes. Streetscape scale applications, however, present a number of design challenges not faced in larger scale applications. Successful design, therefore, requires an innovative approach, and a close collaboration between designers, engineers and environmental specialists at all stages of the project.

The final concern relates to aesthetics and visual appearance, a significant factor in gaining community support. Installations in highly urbanised areas may require a more formal, geometrical and hard edged design than in suburban streets, where a more “naturalistic” approach may be appropriate. Raingardens can be integrated with other design elements such as seating, creating visual interest in the street. Self irrigated landscape features enhance opportunities for urban greening. A high standard of detailing is also required. Some early examples of raingardens used standard civil engineering details and failed to enhance the streetscape or gain community acceptance. Some early details also resulted in higher ongoing maintenance requirements. More recent examples have adopted a creative approach to materials, detailing and planting.

Another streetscape-scale WSUD application for stormwater harvesting is being trialled by TREENET. Initial trials in 2003 were undertaken through a partnership of Transport SA, the City of Mitcham, TREENET and the Urban Water Resource Centre at UniSA in Claremont Avenue adjacent to the Waite Arboretum. The trial focussed on watering street trees by diverting road run-off from the gutter and storing it in the verge. Such a system will help street trees that suffer during periods of drought and improve water quality downstream. Another benefit is a reduction of damage to infrastructure (such as pavements) by roots that flourish in locally resource rich areas, such as kerb-footpath junctions and in the zone immediately below pavements. The trial is investigating low cost and easily maintained options to harvest road runoff, clean it by filtration and bioremediation, and store winter rainfall in the subsoil for access by street trees in dry periods. The production on new root arrays in the verge parallel to the kerb and footpath will reduce conflicts between tree roots, and infrastructure. Many prototypes for a TREENET inlet have been trialled since 2003. The latest version developed by TREENET in partnership with Thebarton Senior College will be demonstrated at this Symposium field day along with other devices developed by the City of Unley. The TREENET inlet was developed with the assistance of NRM funding and will be made available to Local Government and Developers to trial.

Site-specific designs should respond to local context and involve a creative response to site constraints. Successful installations should “value add” to the streetscape in terms of function, aesthetics and ecological sustainability; delivering multiple benefits to the community. An integrated natural system approach, where social and cultural layers are overlaid with the biotic and abiotic layers to create an urban ecosystem, can provide for water storage and re-use, as well as providing green corridors for biodiversity and pollution filtration. This approach is in contrast to the usual interventions that one would expect in a city environment - the replacement of natural ground surface with impervious hard paving, reduced vegetation or biomass, and the redirection of stormwater away from the site, where there is a lack of water infiltration into the soil, no nitrogen fixing in the soil, and no soil respiration. As an integrated system, water is not considered in isolation. In addition to reducing stormwater runoff, the reflected heat load (the heat island effect) is reduced, there is additional habitat and corridors for wildlife, and the location becomes more attractive for people to use as a commuting link and as a place to relax and spend time.

Conclusion

Two-thirds of the Australian population already live in the five largest cities and that continued migration to urban areas is increasing. The quality of the urban environment therefore already influences the health of the majority of Australia's population. The tough water restrictions induced by recent droughts, and the nature of the climate leading to a consequent plant die off, have made people more aware of gardens and plants that are best suited to Adelaide's environment and climate. People now think more seriously about plant choice and nurseries have seen an increase in sales of native and low water use plants. Selecting the right plants can result in significant water savings. An Adelaide garden with native or drought tolerant plants and grasses requires up to ¾ less water than a garden composed of exotic species. Water restrictions have also stimulated people to become more involved in finding solutions to current water problems. For example, more people are now considering alternative water sources, such as installing rainwater tanks and the use of greywater for watering the garden.

The downside to water restrictions is that urban vegetation, gardens and street trees are still deteriorating due to lack of water. The decline of this green infrastructure affects the people of Adelaide and their quality of life, as urban vegetation provides a wide range of benefits to the community. An additional challenge to be faced will be the potential impacts of climate change on Adelaide's vegetation. As we move into the century of climate change, increased understanding about the importance of the urban ecosystem and its connection with surrounding ecosystems and the human and other communities they support will require more sophisticated forms of environmental management. Sustainable environmental management will include the management of a sustainable level of urban vegetation across Metropolitan Adelaide.

Green infrastructure provides important ecological services and enhances the quality of life for the people of Adelaide. The most obvious of these benefits is that gardens are aesthetically pleasing and gardening is a popular and enjoyable pastime for many people. Urban vegetation also plays an important role in moderating the local climate, including the 'urban heat island' effect. A decline in vegetation would lead to increased city temperatures and therefore, an increase in the use of energy-intensive air conditioning in summer. Trees also moderate the local climate by creating windbreaks which reduce the amount of heating needed in the cooler months. Urban vegetation improves the air quality in cities by taking up carbon dioxide, producing oxygen, and filtering air borne pollution and particulate matter. Plants and trees also slow water run-off, helping to reduce erosion. Without this service, the quality of stormwater run-off would decline, as would the water quality in creeks and waterways. Finally, urban vegetation creates habitats for wildlife, such as birds, insects, bats, reptiles and small mammals.

Ahead of us in greater Adelaide lies a brave new world. It is a world of rapid development to the north and south, urban renewal, changing water technologies, supplies and restrictions, and a changing climate. The pressures exerted by each of these are extraordinary. The geographic and demographic circumstances result in varied experiences, pressures, responses and opinions. The only certainty is that significant change is occurring and will continue to radically impact the water story of every local community and environment. Changes to landscape as well as to building design require innovative and flexible systems and thinking. Community education will be a critical element of future policy, programs and activity. Urban landscapes, human attitudes and behaviours are firmly locked into an evolutionary process and, whereas not so long ago it was often the vision and passion of individuals that resulted in change, the future appears to be far more connected to a collective sense of urgency in achieving greater sustainability.

FIRE, TREES AND CLIMATE CHANGE

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Introduction

The Black Saturday fires that occurred on 7 February 2009 in Victoria conjure images of destruction, damage and death. These fires, like those of Ash Wednesday in 1983, and more recently in Sydney, South Australia, Western Australia and Canberra, are seen as devastating and catastrophic to the natural environment, human life and property. They are also reminders that southern Australia has a long history of major fires that regularly punctuate the historical record of the past 150 or more years. The fossil record indicates an even longer record of major and frequent fires (Gill and Groves 1981).

Parts of southern Australia are among the most fire prone places on earth – only parts of Mediterranean Europe, and the southern parts of the USA are rivals for frequency and intensity of fires. Bushfires are not destructive in the natural environment. They are part of the normal ecological cycle to which native plants and animals have adapted. There are individual plants and animals that die during a fire, but populations and communities continue. Communities that are known and loved by many Australians are often dependent on fire and without fire their future survival is jeopardised.

There were reports that the recent fires were the worst ever and that everything had been killed and that there would be little, if any, natural recovery. Even the soil was said to have been destroyed. There was also the now usual kneejerk reaction against native vegetation, particularly in peri-urban areas. As a consequence there have been questions about the role of vegetation in peri-urban parts of Australian cities, especially as climate change is likely to result in more extreme fire weather and more fire prone days (Moore, 2009).

The action of fire on plants and their ecology

At a time of climate change when the weather patterns in many parts of Australia (in terms of rainfall, higher temperatures, higher wind speeds and wind direction) have already changed, it is essential to recognise what fire does to plants. There are a number of components to understanding the effects of fire on plants, including intensity of the fire (often measured as temperature), the duration of the fire and the frequency of how often fires occur.

Some plants are burnt where there is a high temperature, irreversible oxidation of plant materials. If the intensity and duration of the burning are high enough, then the plant part or plant as a whole may be killed. Other plants are singed, which is essentially superficial burning and those parts of the plant or the whole plant have prospects of recovery. Finally, plants may also be scorched by the blasts of hot air from the strong winds associated with bushfires.

The effects on plants of burning, singeing and scorching are quite different, and plants respond variously to the effects of fire depending on the adaptations they possess to fire and stress in general. Adaptations may be structural, physiological or ecological and some of the adaptations of eucalypts to fire (Table 1) serve as fine examples of the typical adaptations of the components of the Australian flora more generally to fire (Gill and Groves 1981). The possession of some, or all, of these adaptations is also an indicator of likely species survival of fire. Consequently different species must be managed in different ways after the fire.

From an ecological perspective, fire removes competition and allows high levels of light to reach the forest floor. Many, and often large, mushrooms and "toadstools" appear which are often the fruiting structures of the mycorrhizal fungi associated with tree, shrub and grass roots. Usually soils are not killed by fire but enriched with nutrients. Signs of recovery are often in evidence 10 days after fire if there has been rain. Many people are up-lifted, given hope and impressed with the speed of recovery.

In the smooth-barked eucalypt communities, such as mountain ash (*Eucalyptus regnans*) forests, the effects of fire are swift, sure and predictable. Individual trees are very sensitive to fire and almost all that are burnt are killed (Moore 1995). However, within weeks of the fire, the fruits and foliage on the trees at the time of the fire are shed, providing both a nurturing mulch (or ash bed) and a rich seed source for the regeneration that follows.

Table 1. Some common adaptations of eucalypt species to fire that can affect their survival and recovery from bushfire (from Moore1995)

Common Eucalypt Adaptions To Fire
• Thick bark. • Sclerophyllous leaves. • Epicormic buds. • Lignotubers. • Woody fruits. • Fibrous/stringy bark. • Volatile oils in leaves. • Seedling regeneration after fire.

In mixed eucalypt forests, such as those of messmate (*E obliqua*) and peppermint (*E radiata* and *E dives*), regeneration occurs not only from seed, but many individual trees survive the fire, and epicormic shoots and lignotuberous shoots emerge as the communities commence a new cycle of growth within months. Lignotubers, probably better known as mallee roots or as basal burls in the northern hemisphere, are found in many Australian species and provide a rapid and sound replacement of a tree.

Epicormic buds are dormant buds that are found just under the bark of many eucalypts, and like the dormant buds found in oaks and elms amongst many other species, provide for a very rapid canopy replacement. Initially however, they are often weakly attached and so if they occur low down on the trunk they have to be managed to ensure that they do not get too long and too heavy. As time goes by, each growing season a new tree grows over the old wood and so a proper and strong branch attachment develops.

In the past after fires, bulldozers often piled ferns and tree ferns into great heaps on the assumption that they were fire sensitive and had been killed. In fact, the opposite is the case, and the growth habit of the rough tree ferns (*Cyathea australis*), and to a lesser extent the smooth tree fern (*Dicksonia antarctica*) and many of the ground fern species (*Polystichum sp., Blechnum sp.*) is such that they are unlikely to burn and as a consequence are fire resistant. The fibrous leaf bases hold a great deal of moisture and are slow to burn (Moore 1995). These characteristics provide protection for the growing apices and so ferns suffer little damage. They have been defoliated, but soon produce new fronds and show a full recovery.

Many of the mountain and peri-urban landscapes burnt in recent fires were renowned for their conifer collections. It is often assumed that conifers are very fire sensitive and as a consequence many trees are felled in the days immediately after the fires. While most pine and cypress species are sensitive, not all conifers are killed by fires, and some are renowned for their longevity and fire resistance. The thick bark of the redwoods renders them fire resistant, and some of the deciduous conifers also cope well with fire. Often these trees are removed after fire unnecessarily, causing major impacts on the landscapes they once dominated.

For other exotic plants, whether they are killed or survive fire depends upon the nature of their injury, their growth habit and adaptations. Many rhododendrons burnt in the fire were killed, but those that were scorched by hot wind blasts, while looking rather sorry suffered little more than defoliation and soon produced new leaves and shoots.

For other plants, although the stems and foliage were killed in the fires, the root systems remained alive and suckers soon emerged. Regeneration from the rootstocks is not only useful, but provides a rapid means of re-establishing valuable vegetation. However, caution must be exercised because for grafted specimens, such as many exotics, the rootstocks may not only be the wrong variety, but in some cases are different species that are not wanted in the garden. This scenario is amply demonstrated in the recovery of rhododendrons, roses, wattles and olives amongst other species.

For bulbous and cormous plants the fire has no real effect on their subsequent growth, apart from providing a boost in nutrient and light levels and the removal of competition. Indeed, following the fires, the displays of such plants, including native orchids in the following May through to September is often spectacular. For certain of the rhizomatous species, the effects are similar and fire has little impact upon subsequent growth.

Assessing the effects of fire on urban vegetation

In the days immediately after a fire it is essential to identify those plants that have survived and those which have succumbed to fire. The cleaning up exercise after a fire is usually conducted by emergency services officers who have little arboricultural knowledge, but who are often proficient with chainsaws. Importantly, the cleanup is conducted at the expense of the State as no charge is made to individuals for the work done as part of the mopping up, including pruning or removing trees. Trees that are left and which subsequently die have to be felled at the property owner's expense, which can readily mount to tens of thousands of dollars in a large garden containing many trees. However, it was interesting that after the Victorian Black Saturday fires of 2009 many more arborists were involved in assessing tree condition after the fire and in particular along roadsides and in public open spaces than had happened after previous fire events. This is a development in post-fire management that is to be applauded.

It is essential that ecological and environmental values inform any mopping up operations that follow bushfire. Where possible, mopping up should be avoided as it can degrade the environment through compaction of soil, the elimination of microhabitats and disturbance to natural regeneration processes. However, where it may be necessary it should be managed under the direction of experts who have detailed ecological and plant knowledge for sustainable environmental outcomes rather than as an engineering based "clean up". Too often mopping up destroys healthy plants that would readily recover from fire, alters edaphic conditions through compaction and changed soil contours and drainage, and eliminates the microhabitats that facilitate the diverse regeneration that follows fires. It is often no more than a form of approved environmental vandalism!

In relation to the mopping up of vegetation after previous fires, following a more thorough examination of the trees that are left standing and those that are felled, a rough rule of thirds seemed to apply to the vegetation of fire damaged trees:

- About a third of the trees left standing were dead, or so badly damaged that they should be felled.
- About a third of the trees felled were alive and would have survived as useful trees after the fire.
- About a third of all the trees affected by the fire were incorrectly identified as dead or alive.
- About two thirds of the trees were correctly assessed and therefore were well managed.

This general rule suggested that many of the decisions made after fires concerning trees are little more than guesses with a two in three chance of getting things right. However, the outcomes of these decisions can have a profound effect on subsequent fire recovery. A dead tree left standing may cost thousands of dollars to remove after the mopping up period, and trees that add great value to streets, gardens and landscapes and which have significant environmental value are removed in error.

The assessment of tree condition after fire can be difficult, but a number of simple criteria can be used to assess plant condition (Table 2). In woody species it is important to determine whether the cambium has been damaged by fire. This can be done on young tissue simply by pealing back the bark and looking for the bright green or light to pale brown cambial layer depending on the species. Dark brown layers normally indicate that the plant is dead or dying. Another symptom worth looking for is the lifting of the bark from the cambium or the development of substantial cracks in the bark which indicate that the cambium has "stewed" in the heat and that bark and wood have separated.

In older parts of the plant, especially for thick barked species, it might be necessary to tap the bark to see if it has lifted from the cambium or to remove a small section of the bark to allow cambial inspection. If the cambium is dead, that part of the plant or the whole plant needs to be removed. In ferns the soft and usually moist fiddleheads in the crown are a sure sign that all is well and that recovery is imminent. Making a correct diagnosis of plant condition after fire can save a great deal of money, time and effort in restoring a landscape.

In assessing tree condition after fire a diagnostic accuracy in excess of 95% is certainly achievable with species that are common and where there is a history of management post-fire. After the 2009 fires several hundred specimens of native pine, *Callitris preisii,* were assessed on the Horsham Golf Course. There is little information on the post fire recovery for the species and so the criteria listed in Table 2 were used to determine whether the trees were dead or alive. The presence of a whitish resin at the base of the trunk proved to be a good indicator of death or survival. If resin occurred around the entire base the tree was assessed as dead, and if resin was present for less than 40% of the circumference then there was a chance of survival. Subsequent investigation of the specimens revealed that when resin was present around the entire circumference 100% of the trees were dead and when 40% of the circumference was free from resin there was an 80% chance that the trees were still alive six months after the original assessment.

Table 2. Criteria that are useful in determining likely plant survival after fire (Extended from Moore 1995)

Criteria for Assessing Plant Condition
• Cracked and lifting bark. • Bark separated from the cambium and sapwood. • Dead cambium (discoloured/dark brown tissue under bark). • Ringbarked major branches or trunk. • Ringbarked trunk at soil or mulch surface. • Dead or seriously damaged roots. • Presence of dormant buds. • Presence of epicormic buds. • Presence of lignotubers. • Capacity for suckering. • Possession of bulbs, corms and rhizomes. • Possession of thick insulating bark. • Possession of woody, fire resistant fruits. • Protected meristems (such as apical buds protected by fruits or fiddleheads protected in the crowns of ferns). • Presence of resins oozing from cracks in the bark at base of trunk.

It is also worth noting that the adaptations described earlier for eucalypts (Table 1) are also possessed by many other species, both native and exotic. For example, some specimens of the lilly pilly (*Acmena smithii*) can possess a lignotuber; some species of elms possess epicormic buds; many species of shrubs and trees have thick bark; sclerophyllous leaves are possessed by many native and exotic species; and, of course, many species possess woody, fire resistant fruits. In evaluating the chances of survival of these species, it is worth considering their adaptations and the likelihood of their survival.

Pre-fire landscape management

In parts of Australia fire is part of the ecology of plant communities and does neither harm nor good; it is simply part of nature's cycle (Gill and Groves 1981). In such places natural fires should be allowed to take their course and in managing such areas, the inevitability of fire must be recognised. If people are to live in these places, as part of peri-urban sprawl, their homes must be properly constructed and appropriate fire prevention plans and techniques implemented which will allow such fires to burn without threatening the property or the lives of people who live within or adjacent to natural forest communities.

In urban areas where the vegetation of streets, parks and gardens are often a mixture of native and exotic plants, bushfires present some interesting challenges. While all plants are flammable given the right conditions, some are fire resistant or retardant (Table 3). Some of the native plants are well-adapted to fire and survive, others may be killed but regenerate readily from seed. Many exotics however, lack adaptations to fire and have to be managed if the landscape is to be re-established properly and quickly.

Table 3. Characteristics of fire retardant tree species (from Moore 2009b)

There are really no non-flammable trees. However, there are low flammability plants which have the following characteristics:
• Green foliage during the fire season. • High leaf moisture and mineral salt content. • Low levels of dead canopy material, especially bark. • Capacity to compete with and suppress grasses and other understorey species. • Capacity to survive droughts and occasional fires.

In planning and managing landscapes from a fire perspective it is important to consider the use of fire resistant and retardant species (Table 4). Fine fuel loads in the vicinity of buildings must be managed through raking, use of low growing species, and by keeping any mulch moist thereby reducing its flammability.

Table 4. A selected and indicative list of some fire resistant and retardant Native and Exotic tree species (modified from Moore 2009b, Cheney 1985, Anon, 1980)

Some Selected Fire Resistant and Retardant Native Species		
Acacia bailyana,	*A howitii*	*A mearnsii,*
A dealbata	*Angophora species*	*Atriplex nummularia*
A vesicaria	*Casuarina species*	*Myoporum species*
Rhagodia baccata	*R nutans*	*Banksia marginata*
Banksia integrifolia	*Hymenosporum flavum*	*Lophostemon confertus*
Eucalyptus bauerana	*E gummifera*	*E leucoxylon*
E cladocalyx	*E blakelyi*	*Agonis flexuosa*
Corymbia maculata	*Melia azedarach*	*Melaleuca armillaris*
Tristaniopsis laurina	*Grevillea rosmarinifolia*	*Brachychiton species*
Syzygium australe	*Elaeocarpus species*	*Pomaderris species*
Bedfordia species	*Ficus macrophylla*	*Lagunaria patersonii*
Pittosporum undulatum	*Solanum aviculare*	*Hakea salicifolia*

Some Selected Fire Resistant and Retardant Exotic Species		
Acer negundo	*Acer campestre*	*Malus species*
Prunus species	*Arbutus species*	*Pyrus calleryana*
Magnolia Grandiflora	*Linden species*	*Quercus canariensis*
Cercis siliquastrum	*Ulmus species*	*Liquidamber styraciflua*
Populus species	*Camellia species*	*Photinia glabra*
Quercus species	*Sorbus aucuparia*	*Delonix regia*
Ligustrum lucidum	*Citrus species*	
Note: Where a genus is listed, there may be many species which are fire retardant, but the most appropriate species within the genus are those that best meet the criteria listed in Table 3.		

However, it should be remembered that vegetation can have many beneficial effects in terms of fire behaviour and fire management (Table 5). These benefits are often forgotten in the immediate aftermath of a fire, and in the frenzy of tree removals after fires the subsequent costs of vegetation removal can be quite significant. After the Black Saturday fires of 2009 one property owner was unable to rebuild because the insurance companies deemed the block of land unstable once all the trees had been removed and the stumps ground. The risk of landslip was simply too high!

Table 5. Benefits provided by trees for a fire management regime

Benefits Provided By Vegetation For Fire Management
• Depending on tree density, trees can reduce wind speeds, slowing the rate of spread of fire and allowing the possibility of better fire control. • Depending on topography, trees can reduce swirling of the wind and so ease fire defence. • Depending on topography and wind direction, trees may deflect fires, especially crown fires over the top of buildings. • Some species smolder rather than burn. • Canopies can act as spark or ember arresters and so reduce the spread of fire on properties and the fire risk to buildings through ember egress. • Roots can stabilise and consolidate steep slopes considerably reducing the risk of land slippage. • Presence of trees before and after fire provide all of the usual ecological services such as shade, humidification of the air, wind speed reduction, reduced erosion and diminished water run off among many others (Moore 2009a, Moore 1997).

Clearly there are also risks associated with vegetation and bushfires, especially near homes and particularly in the more densely populated peri-urban and urban sections of cites (Table 6). Overhead powerlines have long provided a risk in terms of the possibility of tree trunks and limbs clashing with conductors, but the undergrounding of such services could virtually eliminate such situations. The management of litter and especially that which contributes to the fine fuel load has been a recommended goal of fire management near buildings for more than 40 years. However, it does not necessarily mean the elimination of trees and vegetation.

Hollow trees are great habitat trees and should be preserved where possible but when they occur near buildings in a fire prone place they should be removed as they burn hotter and throw sparks further than intact trees. Trees with all or major portions of their canopies dead must be managed as they not only provide fuel for the fire but present a falling hazard during the fire event, which is not only dangerous to life and limb, but can also make fighting the fire more difficult.

Table 6. Risks associated with fire and vegetation to be considered as part of management plans (Modified and extended from Cheney 1985)

Risks Associated With Fire and Vegetation
• Trees growing near powerlines may clash with conductors and increase fire risk. • Litter from trees can accumulate and so increase fuel load. However, this aspect of trees can usually be managed through proper fire planning such as raking and composting of litter. • Trees with fibrous bark may exhibit firebrand behaviour that can lead to spot fires many kilometres ahead of a fire. • Hollow trees can provide a chimney effect that throw sparks and which can make firefighting difficult and dangerous. • Damaged and dead trees may fall or become dangerous during and immediately after a fire. • Plan for a 20m area around the house that is free from flammable fuels. This may be achieved with lawn, paving, gravel, low flammability plants and/or raking to minimize litter and fuel accumulation. • Replace any stringy barked trees close to the house with smooth barked, evergreen, fire-retardant species. This will reduce the risks of fire brands and embers landing on the house. • Regularly manage fuel reduction through raking and proper garden design and management. • Design for fire and make use of fire retardant species. • Ensure that any house is properly designed to cope with fire and to deal with embers that might attack the property. • Construction materials for housing in fire prone areas must be capable of coping with fires and high temperatures.

A Royal Commission vegetation aftermath from Black Saturday

The Royal Commission into the Victorian Black Saturday fires made a number of recommendations in relation to the future management of bushfires. One of the recommendations deals with control (prescribed, or fuel reduction) burning and advised that the State should adopt a policy that at least 5% of public land be burnt each year (Anon 2010). This effectively means that three times more public land would be burnt than is the current practice. It is anticipated that the State is likely to burn more than this minimum and many people in various communities are advocating burning 10-12% of the public land area.

There are good reasons for supporting the strategic use of control (prescribed, or fuel reduction) burning as one of the tools of fire management, but concern must be expressed over the simplistic approach to its use in fire management. It should be considered as part of an appropriate fire management regime, but it should not be too broadly applied and its place should be at the interface between natural plant communities and human habitation. Any use of prescribed burning should involve a proper cost benefit analysis, which looks at its sustainability over the longer term and not just on its use as a fire management tool. The full environmental costs of its use should be evaluated when considering the benefits that it may have in fire management.

It is concerning that controlled burning, is often presented as a panacea for dealing with fire and that it comes at no environmental cost. Rarely is there any media coverage of the impacts of controlled burning on any of the following:

- The risks and frequency of controlled/prescribed fires escaping, the costs of such escapes, and the legal liabilities associated with such escapes.
- The loss of biodiversity in plant communities that are prescribed burnt.
- The loss of biomass in such communities and the subsequent risks of landslides, erosion, silting of rivers and streams, and the impact on water quality and aquatic habitats.
- The loss of nutrients such as nitrogen among others from ecosystems as a result of such fires.
- The large scale release of the Greenhouse Gas, carbon dioxide, on a regular basis further contributing to climate change, and exacerbating the potential for further extreme bushfire conditions.
- The risks associated with the increased spread of pathogens, such as *Phytophthora cinnamomii* among others that may be due to prescribed burning at frequencies that are too high. Such a risk could be devastating in those parts of Australia such as Victoria, Tasmania and to a lesser extent South Australia where many of the forests are dominated by eucalypt species from the subgenus *Monocalyptus* which seem to be susceptible to such pathogens when fire regimes are altered to high frequency, low intensity fire through imposed prescribed burning management practices.
- The effect of prescribed burning on water catchments and its associated environmental and economic costs, not to mention reduced water yields, which would be compounded by climate change.

It is worth remembering that in 1983 in South Australia, areas that had been prescribed burnt carried crown fire with intensity equal to adjacent areas that had not been managed in this way. The same thing happened in the Black Saturday fires as fires were carried in areas where there had been other major fires in the preceding few years. The idea that prescribed burning will solve all of the problems associated with fire is not only simplistic, but dangerous as it could lead to a widespread sense of false security. The crown fire component of fires is where the most dangerous radiant heat is generated.

Another recommendation of the Royal Commission is that overhead powerlines should be undergrounded (Anon 2010). This has proved to be a contentious recommendation as many believe that it is required in bush fire prone areas of the State but its multi-billion dollar cost has been emphasised. There have been media claims that undergrounding the system would add 20% to electricity bills for the next 20 years.

However, the whole debate over this recommendation has been distorted. Few, if any, of the reduced economic costs captured by undergrounding have been factored into the debate to compensate for the higher installation costs. Among the many from an incomplete list of benefits are the following:

- Lowered pruning and line clearing costs.
- Lower long term infrastructure maintenance costs.
- Fewer pole and vehicle accidents and the associated savings in health and social costs.
- Reduced damage and outages during storm events that are likely to be more common under a climate change regime.
- Reduced cost associated with fires and the mopping up operations that accompany them.
- Improve amenity values of streetscapes and the appreciation of real estate values because of them.
- The higher value of a modern electricity distribution infrastructure which has to be replaced as it ages anyway.

From an urban landscape management perspective, undergrounding electricity supply has advantages that far outweigh costs. Not only are there considerable environmental benefits, but the reduced or discontinued pruning regimes would see far more carbon sequestered in trees left standing. While the media debate has focused only on the installation cost, it likely that these will be fully offset, over time, by the reductions in maintenance and environmental benefits that accrue from undergrounding services. Needless to say undergrounding would be achieved by boring under trees rather than open trenching so that there would be minimal root damage

Conclusion

In much of Australia fire is an ecological factor that requires thoughtful, visionary and professional management. It is disappointing that in parts of Australia such as Victoria, South Australia, New South Wales, Tasmania and some parts of Western Australia which are among the most fire prone regions on the planet, the lessons of fire history and vegetation recovery have not been better learned.

Landscape design and species selection must be integrated with an understanding that fire must be part of management plans. Climate change will see a greater fire risk for much of Australia, with more extreme fire weather days, stronger winds from different directions and higher temperatures. At the same time however, the value of vegetation and trees in particular, especially in urban and peri-urban parts of cities, in reducing urban heat island effects and countering some of the temperature increases associated with climate change will be greater than in the past. An overly simplistic reaction to fires that results in large scale tree removal will not serve our society well in the long term, as the many benefits of a vegetated environment would be placed at risk. Management must be about reducing risk but at the same time securing benefits that contribute to the development of sustainable urban and peri-urban environments.

It is certainly possible to have wonderful urban landscapes with all of the aesthetic, health and ecological benefits that they provide in fire prone Australia (Moore 1997). As always, in dealing with environmental and ecological issues, it is a matter of getting the balance right. A focus on one ecological factor to the exclusion of others is usually a recipe for environmental disaster. Poor decisions in reaction to recent fires could easily lead to a degradation of both natural and created landscapes and a loss of the many ecological services they provide. Such an outcome would not only have significant negative economic impacts, but could prove detrimental to human health and well-being.

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ACTS OF GOD: URBAN TREE MANAGEMENT

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Abstract

Broadly speaking, an act of God is a contract or tort law defence for an event (accident) that was caused by natural forces that were outside human control and that could not have been prevented by ordinary skill and foresight. This defence is not commonly used in urban tree management and frequently it is used incorrectly, more often people merely mean that an accident was not caused through negligence.

In ancient times, lightning was the act of an angry God, however an act of God is related to knowledge, as our knowledge changes, so does are ability to apportion blame. Equally, the boundaries of 'ordinary skill and foresight' change.

Severe storms, tornadoes, floods, and other natural disasters occur regularly throughout Australia. The estimated annual cost of natural disasters is $284 million. Tree failures are an inescapable part of such events and damage from tree failures are often a significant part of the costs.

Given that trees are structures and, like all structures, will fail under suitable conditions, can we rely on the act of God argument to defend/excuse tree failures? With our current knowledge of weather, particularly wind speeds, frequencies and loading on trees, is there a point where we can argue that it was acceptable for a tree to fail? From an act of God perspective it is possibly more important that we can demonstrate that human action or intervention did not contribute to the problem, there would be few urban situations where we could easily make such claims. For instance, how many wind connected tree failures are related to inadequate root zones, root zone damage, girdled roots, pruning wounds, planting of poor quality stock, etc?

The act of God defence becomes interesting in light of predictions that the climate is changing and that more extreme weather events are probable and are likely to occur more frequently. Could tree managers be held negligent 20 or 30 years hence when trees we plant now fail due to increased or more frequent wind events, or increased or decreased rainfall? Should we be taking action now to account for these probable future conditions?

An act of God is merely a legal defence where we claim that we have no obligation to pay for the consequences of an event, not too dissimilar to a defence against a claim of negligence. Both are process driven, what processes should be in place to argue an act of God? Robust risk management set within an asset management structure is the simple answer.

We have little data on tree failures and loadings or circumstances where failures occur, it is difficult to be proscriptive at the individual tree level, but at a societal level decisions can be made. I would like to think that the current SA Independent Inquiry into the Management of Trees on Public Land (Ecological Associates, 2010) will be the start of a good societal discussion on the validity of trees in urban environments.

Introduction

How valid is the act of God argument when managing urban trees? What is an act of God? Is lightning hitting a tree an act of God? What if the tree was on top of a hill, near the ocean and fitted with a steel frame to hold Christmas lights? Are urban trees structures? Can we quantify what is a reasonable loading for a tree? We require buildings, signage and other infrastructure to meet specific codes and design requirements. Can we reasonably require the same of a naturally growing living structure which reacts and interacts with its environment and produces a dynamic anisotropic structural material? How valid would such standards be with the predicted changes in climate, particularly, the increased frequency and magnitude of wind events and storms, or merely droughts? How do we explain or 'justify' failures or more particularly injuries or property damage that happens on 'our watch' and what if anything can we do, or what should we do? If not an act of God what shall we call it and where does the 'act of God' sit within a modern 'risk society' (Beck, 1999).

Most urban centres are forests, although the reducing canopy cover and increasing hardscape are challenging the concept. Regardless, the urban forest is an ecosystem (Perry, 1994), and as such, urban forests are not static, but dynamically changing over time and spatially, trees are removed and replaced and new trees are planted. The composition of the forest changes over time as do the relationships with other inhabitants of the forest. However, this tends to occur over a timescale that is far longer than communities and individuals tend to plan within. Similarly the climate constantly changes. The changes are small on a human scale, and hence are difficult to definitively prove, but cumulative.

I am not a lawyer hence the discussion here is limited to a lay person's understanding of the legal terms. What is an 'act of God'? Fortunately its definition does not rely on a religious belief, but clearly that is where the term originated. History provides the basis of this term because from ancient to at least medieval times, misfortunes were explained in terms of intervention by an external force, usually an evil spirit, demon or God (Lupton, 1999). The legal system has adopted the concept and applied a legal interpretation.

At the lay person level the Oxford Dictionary defines an 'act of God' as:

> *'Action of uncontrollable natural forces in causing an accident, as the burning of a ship by lightning.' (Simpson et al., 1989)*

In simple British Law terms an 'act of God' refers to events outside of human control for which no one (including corporations) can be held liable and hence accountable (Merullo and Valentine, 1992). It can have a slightly different emphasis depending on whether it is being considered from a Contract Law or Tort Law perspective. The oldest cited reference I could locate was in Tennant v. Earl of Glasgow, (House of Lords, 1864):

> *'Circumstances which no human foresight can provide against, and of which human prudence is not bound to recognize the possibility, and which when they do occur, therefore, are calamities that do not involve the obligation of paying for the consequences that may result from them.'*

The key phrase that is possibly more relevant today than in 1864 is 'do not involve the obligation of paying for the consequences.'

A similar legal defence that is much wider in scope is *Force majeure*, typically referring to 'forces' or 'events' outside of the control of parties in a contract that effects the performance or outcomes of the contract. Typically cited events include riots, war, crime and acts of God.

From an arboricultural perspective Lilly (2001 p.141) contends that many legal defences based on acts of God fail, she suggests that this is because an 'act of God' is *'...an occurrence due to natural causes that could not have been prevented by ordinary skill and foresight'*, Merullo & Valentine *(1992 p.8)* concur adding the need for *'...the entire exclusion of human agency from the cause of loss or injury.'*

In Australia the Crown in *The Secretary to the Department of Natural Resources & Energy v. Megan Elizabeth Harper* 2000 argued the 'natural' nature of the area – described in the case as 'bush' meant that the event was outside human control and that no human intervention was involved (the Crown was defending a claim of negligence). This reinforces the argument that an 'act of God' must involve situations fundamentally removed from human interference or control. Generally, an act of God will be difficult to establish in urban areas, except in exceptional circumstances and will still probably fail if the defect that caused the failure was known of or should have been known to exist and should have been remedied or removed (Lilly, 2001, Mattheck et al, 1994). Exceptions could include lightning strikes.

The basic argument is about events outside human control and what is really being tested is the required 'duty of care' or more specifically the tort law of negligence. A duty of care is fundamentally the base element of the modern 'risk society'. The test for this duty of care has been increasing in line with societal changes to the point where Justice Gleeson (1991) suggested that in effect 'reasonable care' has reached the point that the test is virtually that of strict liability and therefore no process will protect against claims of negligence.

The key elements for an act of God are:

- What was reasonably foreseeable,
- What could have been done, and
- What level of human intervention exists?

In ancient and medieval times an act of God helped explain the unexplainable. As knowledge, particularly scientific knowledge, increases it becomes more difficult to use an 'act of God' as a reasoned cause for an event. Hence knowledge is the key measure.

How do tree failures in modern societies/communities stand alongside the act of God defence? What could be defined an act of God? Events that are interesting to consider include downburst winds, lightning strikes, tornadoes, severe storms, a cyclone in Adelaide, floods in areas that have never flooded, summer or sudden branch failure. Considering these elements against foreseeability, preventability or human intervention becomes interesting and no doubt debatable.

Lightning strikes

It is likely that more than a thousand people are killed by lightning each year. There are 350-450 lightning caused fatalities each year in the US alone, with hundreds more injured. This data is typically under reported (Curran et al., 1997). Lightning strikes cause fatalities and property damage across Australia. Between 1803 and 1991, at least 650 people have been killed in Australia (Coates et al., 1993). The overall death rate is 0.08 per 100,000, or converted to the current population it equates to an approximate annualised mean of 18 fatalities (Coates et al, 1993). Although the ABS only reported 3 deaths in 2007 and 4 in 2008 (ABS 2010).

It is estimated that over 8 million lightning strikes occur over the earth each day. Lightning is common in Australia with many strikes occurring each day. The ABC reported that one thunderstorm in Darwin produced 1634 lightning strikes, which is more than Perth receives in a year (Australian Broadcasting Corporation, 2002). Some 40% of Darwin's electricity outages are caused by lightning.

We understand when lightning is likely to occur and in many cases, lightning related accidents are somewhat foreseeable. For fatalities the male/female ratio is skewed with the younger male age groups over represented, 60% were work related and 20% recreational. These statistics illustrate that lightning fatalities are not random.

In ancient times lightning reflected the wrath of the Gods, it was undefendable. We understand lightning, the causes, when it is likely to occur. Lightning is tracked and mapped and proactive defensive strategies exist including national standards e.g. Lightning Risk and Protection AS 1768:2007.

Given our knowledge, technical ability, the likelihood and frequency of lightning occurring, can lightning be considered an act of God?

Tornadoes

Many would think these were rare events in Australia. However, the Bureau of Meteorology states that in Victoria some 160 tornadoes have been reported over the last 90 years and that many more are unreported. Perth has the potential for nine tornadoes per year, whilst the average reported number is three (Jones et al, 2005 Chp 2).

Overseas tornado wind speeds have been recorded to 450 km/h. Damage to structures from tornadoes in Australia is not uncommon and they have caused at least 41 fatalities (Middelmann, 2007 pg. 88). Damage from tornadoes tends to be intense but limited to small areas.

Figure 1 August 2010 a tornado passes Moama Victoria. Picture: Herald Sun

The probability of any single building being impacted by a tornado in its lifetime is very low, and it is not a requirement to design structures to resist tornado winds.

Clearly the arrival of a tornado is outside of human control. However is damage caused by a tornado an act of God?

Severe storms
Probably the most common direct reason for tree failures is severe storms (the indirect reasons for such failures is another question). The damage from severe storms is generally less severe than tornadoes and lightning. However the damage is likely to be far more widespread.

Severe storms are relatively common, the average number of severe storms reported in NSW and the ACT is approximately 120 per year (Bureau of Meteorology, 2009). Severe storms produce wind gusts >90 km/h and the most damaging have winds gust of 160 km/h. The strongest wind gust recorded during an Australian thunderstorm was 196 km/h.

In May 1994, some areas of Perth experienced maximum wind gusts of 143 km/h, while winds averaged 107 km/h over a 30 minute period in nearby Fremantle. Damage from such storms is common place and largely to be expected, injuries and fatalities are far less common. Storms account for 26% of the annual cost of 'natural' disasters estimated to be $284 million per annum (The Bureau of Transport Economics, 2001, Blong, 2005) and that severe winds account for around 40% of damage to Australian residential buildings (Blong 2005) significantly more than other natural hazards.

Trees commonly fail in strong winds. In Figure 2 James et al cite the works of Cullen and Spatzin identifying the zones where tree wind throw and breakage occurs (James et al., 2006). These are not uncommon wind speeds, and at the lower end of winds expected in severe storms.

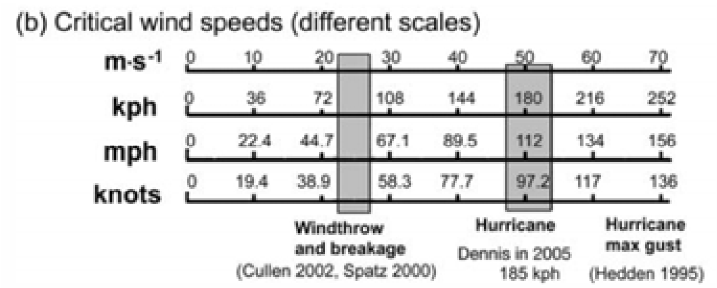

Figure 2 Critical wind speeds from James et al, 2006

In the 12 months from August 2009 the BOM at East Sale (Victoria, Aust.) reported maximum wind gusts exceeding 90 km/h five times and six times in 2006. It would be difficult to argue this data represents rare events. In the Gippsland area the building code of Australia requires new buildings to be designed to a wind speed of 33 m/s (≈ 120 km/h). This is above the point where trees begin to fail.

Once again given the knowledge that severe storms will occur and the frequency of the events, can severe storms be considered acts of God?

Sudden branch drop
Sudden or Summer branch drop is a widely reported occurrence. Harris (1983) describes SBD as 'apparently sound limbs breaking off mature urban trees….during calm summer weather'. Given that he implies, and I do not believe anyone has shown any differently, that this type of failure is unpredictable - can it be considered an act of God?

Discussion
Shigo (1991 p.359) states '*the modern arborist must understand liability and the legal machinery'.* An act of God is a legal defence. It is applied post an event and in effect it is used like other forms of legal defence generally against a claim of negligence. Hence from a tree management perspective there is really little difference from a claim of negligence. Similar questions will be

asked, such as was it foreseeable, could or should have anything been done, or was it uninfluenced by human intervention?

Slovic (1999) argues that risk is merely a *'social construct'* that changes over time, and that is clear with the act of God defence. For example, lightning was clearly the action of an angry God before we understood what caused lightning.

If we break down the House of Lords 1864 statement in Tennant v. Earl of Glasgow we end up with two key assessment statements.

- Circumstances which no human foresight can provide against.
- Of which human prudence is not bound to recognise the possibility.

These are a stronger criteria than the more recent Lilly's (2001 p.141) and Merullo & Valentine (1992 p.8) definition:

> *'an occurrence due to natural causes that could not have been prevented by ordinary skill and foresight'.*

It is difficult for public authorities to argue that they do not have a duty of care to 'ensure that all persons who are so closely and directly affected by our acts or who rely on us for their safety are not placed in a position of risk' (Whiteside, 1991 p.30). To prove an event was an act of God and hence that the land manager was not responsible, a land manager will be required to 'prove' that the incident was largely not preventable and that human intervention was not the cause. Consider the following scenarios from a tree management perspective.

Lightning strikes
Clearly it not possible to predict when lightning is likely strike; although it is somewhat possible to estimate where and a probable frequency. Would it be an act of God if you had a 30 metre high Norfolk Island Pine on top of a hill near the sea on which you attach metal fixtures to mount Christmas lights on? It would be a rare situation in Australia where it could be considered reasonable to fit lightning protection systems to a tree. It is common place in parts of the USA, where the national standard for lightning protection even has a section for trees.

Clearly there are scenarios where one would argue that human foresight could have reasonably foreseen the possibility of a lightning strike. Hence, the 'act of God' defence would not be strong. However, whether it was reasonable to attempt to mitigate such a possibility is then a risk management decision based on what is reasonable (that is, acceptable) risk.

Severe storms and tornadoes
Extensive data exists in relation to weather and it is readily available. Severe storms regularly occur over most parts of Australia. Buildings and most structures are required to meet design guidelines, in particular wind loading requirement, these are to 'ensure' a safe standard such that the structures will deal with the likely local loadings.

Depending on the location, all buildings are designed to meet a defined wind speed. In non-cyclone areas this is typically around 33-35 m/sec (120-125 km/h). These wind speeds are possible in these areas although unlikely. Whilst in cyclone areas wind load designs cater for 250 km/h winds.

If the building code designates that for a particular area a wind load design speed of 125 km/h is required, then logically, this must be the point of acceptable risk. That is, someone has made the decision that a structure does not need to be stronger than this. As a tree is a structure then a similar point could be made. However, as previously noted tree failures start to occur at approximately 90-100 km/h and many, if not most, trees would fail at 250 km/h wind speeds.

Is it an act of God if a building fails in winds above its design criteria? In most instances it would be difficult to argue that it was an act of God, unless the winds were beyond human foresight, given the knowledge, data and modelling ability of modern climate scientists this would be significantly stronger than recorded for an area before. As with most other scenarios, wind or storm damage is far more likely to be assessed in terms of acceptable risk and hence was anyone negligent.

What is an acceptable wind speed loading for a tree, at what point can we say it failed above its designed loading and hence the failure was acceptable? For instance, in 2008 a massive storm hit Brisbane suburbs with wind speeds of >100 km/h widespread and a peak gust was recorded at 176 km/h. It was reported that up to 4,000 homes were damaged, with 300 homes 'significantly damaged' and 30 deemed unliveable (The Age November 17, 2008). Needless to say tree failures and damage caused by fallen trees was widespread. However the most interesting comment was the quote attributed to the then Mayor Mr Newman:

> *'Nothing like this has happened to the city for at least 10 years,'...*
> *'Perhaps it goes back to 1985 with a very big storm back in those days.'*
> *(The Age November 17, 2008).*

Whilst no doubt a natural disaster, given the mayor's quote it would be difficult to argue it was beyond human foresight. It is another argument completely to consider what, if any actions could have been taken to prevent damage caused by the event.

Reinforcing the view of predictability, possibly future damage reduction and levels of acceptable risk, the Courier Mail (November 16, 2008) cites an Ipswich City Council planning spokesman calling for a review of building codes because of the level of damage from this storm.

Whilst arguably we have the technology and possibly the knowledge to estimate the wind fastness of trees, or at least the lower limits, (e.g. through the work of Ken James, Wessoly's SIA (Static Integrated Assessment/Methodology)) and other models, these approaches focus on individual trees and situations and are not transferable to populations of trees. Nevertheless what would be the consequences if the data existed where it could be shown that trees growing in suitable conditions had 'X' wind fastness, and that there was a 25% probability that winds would exceed that level in 1 in 20 years?

Sudden branch drop

Sudden or summer branch drop (SBD) is interesting from a tree physiology and a risk management perspective. Little or no data exists to aid predicting as to when a branch will fail due to SBD. Some preconditions are often stated but I doubt many would/could justify a probability of failure placed on a branch as more than intuition.

An act of God fundamentally precludes humans being able to stop the event occurring, and also the lack of human intervention in the cause. It is probably reasonable that our limited knowledge of SBD does mean we can do little to prevent an event, and in most instances it is probably not caused directly by human intervention.

However I doubt we can really consider SBD *per se* as an 'act of God'. We are aware of it occurring, we have some idea of the conditions required for it to occur and in many areas we have historical data to confirm it occurring, hence can reasonably predict on a broad scale that it will reoccur. In a general sense it is not outside of human foreseeability, however at the individual tree level it is not possible with any degree of certainty to be able to predict a failure.

Can we do more than place advisory signs in places we suspect it might occur to warn people of the potential? The moment we place a sign, we acknowledge that it is not an act of God because foreseeability is clearly admitted.

Acts of God as a valid defence

As discussed in the above simple examples, it is difficult to suggest that an act of God will be a valid defence in urban areas except in the rarest of instances. Natural disasters may or may not be acts of God in the sense that humanity could not have prevented them, but in many instances the consequences were foreseeable with only a reasonable level of foresight. Floods to houses built in low lying areas, localised flooding due to drainage systems being loaded beyond their design parameters are quite to be expected; as are roofs being blown from houses in winds above the design loadings and many other easily thought of scenarios.

The balance between cost to individuals and the community and the benefits is the reason for building codes and the like. Whilst for instance, it is possible to build structures to withstand 300 km/h winds, the community has decided that the benefits do not outweigh the costs given the likelihood of such events occurring. Insurance is one way that individuals and the community can pay a fee to cover the possibility of unfortunate events happening (insurance companies in effect spread the cost of paying for such events across a large and geographically diverse customer base).

Insurance should be based on cost/benefit analysis, (i.e. how does the cost of insurance compare to the cost of mitigating the risk of damage or injury). Unfortunately, from my experience this approach appears lost on some local government mutualised insurers. For example, CMP in Victoria expects an annual inspection of all park and street trees, but they will not provide any information so that councils can compare the cost of this against other options. Wellington Shire Council has some 35,000 planted urban trees, therefore even a quick inventory style inspection will cost around $100,000 per annum. This represents some 20% of the annual recurrent maintenance budget (which is based on a 3-year cyclic pruning program). Would spending $100,000 per annum on inspections at the cost of $100,000 per annum less on works reduce the risk? I would suggest not.

Where does this leave the management of trees? Acts of God fundamentally will not apply to urban trees. It is doubtful we could argue that many trees are unaffected by our actions, and whilst few trees fail under 'normal' weather conditions, 'normal' trees appear to start failing at wind speeds greater than 100 km/h and such wind speeds are not uncommon in many urban areas.

This is possibly caused by two factors. Firstly, the commonly cited argument that most trees are derived from forested situations, and hence structurally are less adapted to being isolated trees (although I have yet to see any peer reviewed data supporting this view and it is contrary to Mattheck and Breloer's 1994 axiom of uniform stress). Secondly, it is a matter of population genetics; the strongest survive for a set of given conditions and little or no natural selection has been applied to urban trees. Although it could equally be argued that trees are as strong as they need to be and the loss of trees and branches in storms is a normal part of a treed ecosystem, increasing the likelihood of bio-diversity and a reduction in even-aged stands.

If trees begin to reach their design limits at winds speeds over 100 km/h, it must be accepted that occasionally a large number of trees will fail when wind speeds exceed this level. It is not an act of God, but a mechanical limitation, the result of a natural design limit. Many trees do not fail in wind speeds well above 100 km/h, so is it possible to identify such trees? There is a reasonable chance that highly stable trees could be identified, or at least the circumstances needed to provide for highly stable trees, although given the lack of funding for urban trees it is unlikely such data will be forthcoming.

The reality is that urban trees do not pose a significant threat to the community. This is reflected in the small number of fatalities caused by trees and the limited costs borne by the community for tree related damage.

Hoy and Holley (2004) in a report for Melbourne University extracted tree related fatality data from the National Coroners Information System database for the period July 2000 – November 2004. This identified 17 non-work related fatalities due to trees across Australia. Simplistically this can be expressed as a societal risk of 1:5.2 million per annum. Further analysis divided the data into rural and urban fatalities, resulting in an urban fatality rate for the 53 months of five and hence a societal risk of 1:17.7 million per annum.

Forbes-Laird (2003) in the UK Tree Forum claims that in Great Britain 32 fatalities and 22 serious injuries occurred over five years (1998-2003). This includes non-industry accidents in rural, urban, roadsides, and forested areas. This data has not been substantiated. Whilst any death will be seen as tragic, given that some 57 million people live in Britain (National Statistics, 2004) this suggests a tree-accident fatality rate 1:8.9 million per annum and a 'serious' accident fatality rate of 1:5 million per annum.

Injury rates are difficult to identify. Dunster (2003) suggests that little information exists as most tree related injury cases are settled out of court. As the judicial system provides greater compensation in the case of injury it could be considered that severe injury is potentially the greatest financial risk for public authorities.

Damage caused by trees directly or indirectly is difficult to quantify. Barley (1990) in discussion of '*injury from roadside trees*' presents a small amount of information provided by Melbourne City Council in relation to branch failures onto vehicles, however it is not detailed nor extensive. Typically mutualised local government insurers do not make such information publically available. Fortunately, the current Independent Inquiry into Management of Trees on Public Land (Ecological Associates, 2010) provides a limited but interesting 'snapshot'.

The SA Mutual Liability Scheme (MLS) reported 2759 tree related claims over a 20 year period (July 1989 – May 2010), of which 55% lead to damage or injury from fallen trees or failed branches. This translates to a mean of 76 claims per annum for South Australia. With a December 2009 South Australian population of 1,633,900, this broadly equates to damage or injury from fallen trees or a failed branches claim rate of 1:21,500 people per annum. They report claims involving pedestrians or cyclists (injury or near-misses) averaging a little over 1 per annum (24 total), giving a claim rate of 1:1.6 million people per annum. To place some proportion to this, in 2009 there were 119 vehicle fatalities in South Australia, giving a fatality rate of 1:13,700 per annum. In Australia during 2008 three people died from dog bites, four from bee or wasp stings, four from lightning, and 169 people drowned (ABS, 2010).

Unfortunately the Issues Paper data provided is very incomplete, and does not allow any in depth analysis. Nevertheless what is provided would seem to indicate that costs from claims made to MLS are low (It does detail that annual claims related to tree or limb failure are approximately 17% of total claims received. However, it does not detail what percentage of the actual costs is apportioned to tree or limb failure). The equivalent Victorian local government insurer is unwilling to supply any information.

Whilst 'acts of God' exist, Australians are an urbanised community, with 87% living in urban situations (2004, ABS, 2003, ABS, 2004a, ABS, 2004b), hence living in a built environment. Some elements of nature, e.g. tornadoes, cyclones, severe storms we will never be able to prevent. Nevertheless, we will become better at predicting them. Humanity and trees are intrinsically linked; communities are not going to accept treeless suburbs. However trees are structures and as such will fail once forces exceed the design loadings.

The greatest unknown that I have not yet addressed is climate change; whether it is caused by humanity is largely meaningless. The CSIRO (2010) predictions are that the effects of climate change will be superimposed on natural climate variability, leading to changes in the frequency and intensity of extreme weather events. Including more extreme fire weather, increased number of hot days, more intense heavy rain, stronger cyclones and increased hail events.

Given our current knowledge and the variable and somewhat inconclusive prediction of climate change can we really claim an act of God in 2060 for plantings undertaken in 2010? Maybe more to the point is that climate change in all likelihood will lead to more urban tree failures and possibly greater damage and injuries. What should we be planning in 2010?

We are a knowledge based society, how much do we know about trees growing in urban areas, what we need to know, what are the gaps in our knowledge. No longer can we claim an act of God when something unfortunate occurs, any post mortem will most likely show that we had the *human prudence to recognise the possibility.*

Conclusions

The act of God defence is weakened as knowledge increases. As knowledge increases humanity, not God(s), have to make the choices about what is acceptable and what is not. The act of God is not a defence for urban trees. The standard we will be held accountable for is that of the tort of negligence (Appendix 1 contains general principles in establishing negligence), and the best defence will not be driven by a fear of litigation, but one driven by suitable consideration of holistic risk management (not risk assessments).

Risk management is:

- an integral part of community processes
- part of decision making
- systematic, structured and timely
- based on the best available information
- takes human and cultural factors into account
- transparent and inclusive
- dynamic, iterative and responsive to change
- facilitates continual improvement

Quite simply, managing urban trees is about managing an asset for now and for the future; that asset is the urban forest. Included in that asset management is the risk management process, however risk should not be the sole driver, because if all of the risk management points above were included in an asset management plan, risk levels would be low by default. Good asset management leads to a low risk urban forest.

The current SA issues paper is an excellent way of engaging the community and to ask the big questions: what is an acceptable level of risk, how much do you value trees, and what are the knowledge gaps?

Whilst writing this paper was a great big picture exercise, the lack of data and the limited research conducted on urban trees was annoyingly apparent. The SA Issues Paper raises some good questions, but we do not have the data to answer most. This is an industry that relies too much on opinion, conjecture and 'common sense' rules.

There are over 600 local governments in Australia and no doubt millions of urban trees. In other industries much of the research is conducted using industry levies, often with matching government funding. Conservatively there are over 5 million urban trees, if an industry level of 10 cents per tree was placed in a research fund, and matched with government funding this would give an annual fund of 1 million dollars. How much targeted research could this produce?

Appendix 1 General principles in establishing negligence

To complicate the issue of trees the law and public authorities, substantial civil liability reform legislation has been implemented in all States and Territories since the landmark High Court's affective removal of the nonfeasance defence in Brodie v Singleton Shire Council(2001). While these changes are substantial, they do not change the generally accepted 'duty of care' requirements typically cited to establish negligence, for instance the Civil Liability Act 2002 (NSW, section 5B) details:

General principles

(1) A person is not negligent in failing to take precautions against a risk of harm unless:

> *(a) the risk was foreseeable (that is, it is a risk of which the person knew or ought to have known), and*
>
> *(b) the risk was not insignificant, and*
>
> *(c) in the circumstances, a reasonable person in the person's position would have taken those precautions*

(2) In determining whether a reasonable person would have taken precautions against a risk of harm, the court is to consider the following (amongst other relevant things):

> *(a) the probability that the harm would occur if care were not taken,*
>
> *(b) the likely seriousness of the harm,*
>
> *(c) the burden of taking precautions to avoid the risk of harm,*
>
> *(d) the social utility of the activity that creates the risk of harm.*

Derived from the NSW Civil Liabilities Act 2002 Section 5B

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WHATEVER HAPPENED TO THE BACKYARD? THE MINIMISATION OF OPEN SPACE IN AUSTRALIAN SUBURBIA

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Abstract

Although a substantial backyard might be considered an iconic Australian feature, by the late 1990s, almost all new suburban houses had minimal provision of soft-landscaped private open space. Quantitative analyses of examples from older and newer suburban form indicate that this phenomenon is happening irrespective of size of lot and appears connected with a trend to larger dwellings relative to lot area. Study of the environmental literature shows that it represents a loss that has serious ecological implications for the community as a whole, including a significant reduction in biodiversity, sustainable drainage and a beneficent microclimate, in addition to lower standards of domestic amenity. Planning codes, while not actually encouraging the trend, do nothing to prevent it.

Introduction

In the early 1990s, a dramatic change in Australian suburban form began (Hall, 2007a, 2008, 2010). The older areas are characterised by tree cover while, in the newer ones, large roof areas predominate and dwellings can be nearly roof-to-roof. This change has not been subtle or gradual in either space or time. It is a phenomenon that is immediately apparent from even a cursory examination of aerial photographs. This change is not something that relates to the backyards alone. House and street design have also changed as part of the same process. There has been a trend towards deep, square house plans possessing large internal spaces with little natural light and ventilation. There is also a trend towards fewer and smaller windows. The narrow gap around single-storey houses is dominated by high opaque fences. The frontage is dominated by integral garages.

Data from an analysis of aerial photographs reveals that, before the 1990s, suburban form incorporated backyards of substantial size, useful shape and a significant coverage of trees. Lot coverages by houses were 20-30% with a maximum of 35-40%. For new construction after this period, provision of large backyards ceased and 35-40% now represents the minimum, rather than the maximum, lot coverage. Although there has been a trend to smaller lot sizes, the phenomenon appears independent of lot area. Examination of local planning regulations provides little evidence that the changes are being driven by planning policy but it is clear that planning policy has done nothing to prevent it.

Most importantly, the evidence from the literature suggests that this change in suburban form has serious environmental consequences. The domestic backyard, including its tree cover, has an ecological function and importance that goes well beyond the interests of the individual household. The smaller proportion of the total land area that is permeable and planted will have an adverse affect on the local ecology and microclimate.

The research method

The first stage of the investigation (Hall, 2007a, 2008) was the visual inspection of aerial photographs of Australian cities. Sample areas were then selected for detailed analysis from within the older and more recent residential suburbs of Sydney, Melbourne, Brisbane, Adelaide and Perth. Measurements were made of the parameters of lots and building footprints from aerial photographs, including backyard area and lot coverage. At the same time, the approximate dates of subdivision and construction, and details of the local planning regulations that applied at that time, were sought. One reason for selecting examples from a number of cities was, hopefully, to take in a range of regulatory regimes. All the examples were inspected and photographed at ground level.

The details of the local planning regulations applying to the examples were reviewed in the light of the relevant planning policy documents at local government and state level. Note was also made of any Commonwealth government documents that might have influenced these over time.

As a separate but complementary exercise, the literature on the role of the private open space around the dwelling was studied. As the investigation proceeded, it became clear that this was an interdisciplinary task embracing on a wide range of ecological and behavioural studies.

The results of the analyses

The results of the analyses are set out in Tables 1-4. An issue in measurement was how to the count the land area occupied by verandas, pergolas and other lightweight structures that are now common as extensions to the Australian home. The terms *net footprint* and *net coverage* in the Tables refer solely to the original dwelling while the terms *gross footprint* and *gross coverage* refer to the dwelling plus the additional structures. The data for the area of the backyard refer only to that space open to the sun.

The data all show a consistent pattern indicating a distinctive phenomenon. There was a clear-cut difference between older suburbs, characterised by contiguous private open space to the rear of properties with extensive tree cover and the newer residential developments with significantly less space between the dwellings. The older form was universal up until the late 1980s. It is possible to find developments constructed during the 1990s that take an intermediate position either by mixing the types or by having backyards that are smaller but still of usable size and shape. However, by the late 1990s, construction of the older form had ceased. No recently built examples with the same characteristics of the older suburban form could be detected. The newer form appeared in increasing strength as the 1990s progressed and was predominant by 2000. If anything, its characteristics have become more extreme with time.

The traditional Australian backyard

The physical characteristics of the traditional Australian backyard were realised over the first 150 years from colonial settlement in the form of the detached cottage with a large yard on an allotment between 600 and 1200 square metres (Cunningham & Auster, 1996). Despite the obvious cliché of the 'quarter acre block' (1012 m^2) which, although existing, is not, or has ever been, commonplace, the critical point is that, until comparatively recently, most suburban houses in Australia have had big backyards by world urban standards (Halkett, 1976; Seddon, 1997; Timms, 2006; Head and Muir, 2007). Based on the size of the genuine quarter-acre lot, and assuming a large house with site coverage of 200m^2, a backyard would be likely to be in the order of 500-600 m^2. A standard sized block in the order of 600m^2, again assuming a large house with site coverage of 200 m^2, would still be likely to accommodate a backyard in the order of 200 m^2. This is confirmed by the examples shown in Tables 1 and 2. The average backyard area is over 200 m^2 except for in Hebesham (NSW), from the 1980s. Even here, 57% of the backyards are over 150 m^2.

For a better appreciation of the implications of these figures, we can take a closer look at three of the examples from those listed in Tables 1 and 2. Figure 1 shows an aerial view of part of the suburb of Camp Hill Queensland (QLD). It lies 5.7 km southeast of the centre of Brisbane and was subdivided between 1945 and 1947. The houses are generally of the "Queenslander" type, the vernacular architecture of the State. The locality is particularly notable for the number of trees both in front and behind the houses. The backyards are of substantial size and usually include facilities for drying clothes, as shown by Figure 2.

Figure 3 shows an aerial view of part of Hebersham NSW, subdivided in the 1980s. It is some 38 km west of the centre of Sydney. The majority of backyards have a significant area and a square shape. A number have swimming pools. Figure 4 shows an aerial view of part of the Perth suburb of Spearwood dating from the 1980s. It is just over 17 km south of the city centre. Most of the backyards are of substantial size and some accommodate a rainwater tank and swimming pool.

All three examples feature good rectangular backyards with trees. Only a few have areas less than 150 m^2 and many are in excess of 300 m^2. The proportion of the total lot covered by the dwelling footprint only occasionally exceeds 40% and, for a very large proportion, it is less than 30%. Net densities are 9-13 dph, low but not excessively so. It does not follow, however, that low density is solely due to the presence of large backyards. A significant determinant of the low residential densities is the very large front-to-front distances, in excess of 30 m. Finally, a very important characteristic of the older suburban form that is very clear from the aerial photographs is the way that the backyards interconnect to the rear of the properties providing a nearly contiguous planted area.

Figure 3 An aerial view of part of the Brisbane suburb of Camp Hill QLD subdivided 1945-1947. The houses are generally of the "Queenslander" type. Note the number of large trees.

Figure 4 A typical backyard in Camp Hill QLD.

Examples of the newer suburban form

Comparing Tables 3 and 4, detailing the more recent suburban form, with Tables 1 and 2, what is striking is the differences in value for lot coverage, backyard area and rear setback. Average net lot coverage is now between 39% and 56% compared with 22%-30%, gross lot coverage is 46%-52% compared with 29%-38% and setback distance 4-7 m compared with 12-29 m. Table 4 shows that the majority of backyard areas in all the newer examples were under 100 m^2.

At first glance, 40-50% lot coverage may not seem too problematic. Would not this mean that half the lot could be garden? Half of a 600 m^2 lot would be 300 m^2 and 30% would still be 180 m^2. The actual situation is counter-intuitive. The calculation neglects two factors. The first is the aggregate amount of the narrow space left around the sides of the dwelling. Figure 5 shows a diagram of a house footprint with a 2 m gap all around it. For a 300 m^2 lot area, say 10 m x 30 m, this gap takes up 48% of the total area giving a lot-coverage of 52%. For a 600 m^2 lot area, say 15 m x 40 m, the coverage is 66%. This narrow gap alone can take up 34 - 48% of the lot. If a dwelling covers half the area of a lot there will be little private amenity space of a useful size and shape. This issue is compounded when the space at the front of the dwelling is taken into account. A front setback of the dwelling from the front boundary of the lot is required in most of Australia. Once this is removed from the uncovered area at 40-50% coverage very little remains at the back and sides.

For a closer look at the newer suburban form, three examples will now be described in more detail. Figure 6 shows an aerial view of a part of Mount Druitt NSW, off Meacher Street, which was constructed in the mid-to-late 1990s to the south of the older Hebersham area previously described. The street scene is shown by Figure 7. Note the dominance of garage doors. In front of fenced front gardens is a wide unfenced grass area and carriageway. Some houses are comparatively modest in scale, or are on corner lots, permitting a fairly small backyard, but most have negligible open space at the rear.

The second example is taken from the Perth suburb of Spearwood but on the opposite side of the main road to the older subdivision described earlier and shown by Figure 4. An aerial view is shown by Figure 8. What is especially remarkable for this example is the low density and large lot sizes. At 13.6 dph the density is nearer to the older suburbs than to the two other recent examples but this has not resulted in the same amount of green space. At over 600m^2, the lots are the same scale as those in the older Brisbane suburb of Camp Hill QLD. While the lot dimensions are large, so are the house footprints. Consequently, the backyards are very small, especially in comparison to the house and lot size. Some of the houses are almost entirely surrounded by others. The street scene, illustrated by Figure 9, is dominated by large paved areas and by wide garage doors. There are few windows and little surveillance of the pubic realm and sense of enclosure of space.

Springfield Lakes is an extensive master-planned development on land lying over 23 km southwest of the centre of Brisbane. The land was cleared in 2000 and construction has continued for nearly ten years. Figure 10 shows an aerial view of part that was completed in 2002. Lot and dwelling size show some variation. Some properties have a distance of 6-8 m at the rear of the house, resulting in a fairly useful back garden, but many have only 2-3 m. For 70% of the properties, the net coverage of each lot by the dwelling footprint, not counting the lightweight extensions, is over 40%. Most have very little space at the back, 93% less than 100 m^2 and 68% less than 50 m^2. The street scene is dominated by garages, unfenced front lawns with hard standings and a wide road reservation. Note the view of the arrangements at the side and rear of a dwelling that is revealed by Figure 11. The meagre space around the house and lack of windows can be clearly seen. The exposure of the side boundary fence is poor for security and unsightly for the street scene. The strip of land in front of it has no apparent use.

Overview of the examples

As we have seen, the older type of suburban form is characterised by substantial backyards of at least 150 m^2 and they may easily be several times this figure. In contrast, in the newer suburbs, although some properties may have backyards of 100 m^2 they are normally much smaller than this and are commonly less than 50 m^2 in area. Not only this, but the narrowness of the gap between the dwelling and the side and rear boundaries of the lot frequently results in this area being in the form of a long strip rather than a more useful square shape.

What also seems to be happening is that the changes in the size and shape of the backyard are closely associated with changes to the design of the house. As is revealed by the aerial photographs, many of the houses in the newer suburbs are deep-plan, in other words there is a considerable distance from the front to the back. Many are also square in plan, with the side-to-side dimensions also being large. The street views reveal that they are predominantly single-storey and that integral garages are almost universal. An integral garage, as opposed to an open carport or detached garage, has the effect of reducing the natural light and ventilation to the interior of the dwelling. Windows are often small and few in number. There is little outlook from the windows for the occupants to enjoy. As the houses are now much closer to each other, to maintain privacy, fences must be high and opaque preventing any visual contact between neighbours. The sum of all these characteristics is that the houses have a significant proportion of the interior space some distance from windows which will be difficult to light and ventilate naturally. The large roof areas will absorb heat in summer, which must be expelled by air-conditioners, and lose it in winter but the dwelling will not be able to replace it with solar gain.

Figure 5 An aerial view of part of the suburb of Hebersham, subdivided in the 1980s in western Sydney NSW.

Figure 6 An aerial view of part of the Perth suburb of Spearwood WA. Subdivided in the 1980s.

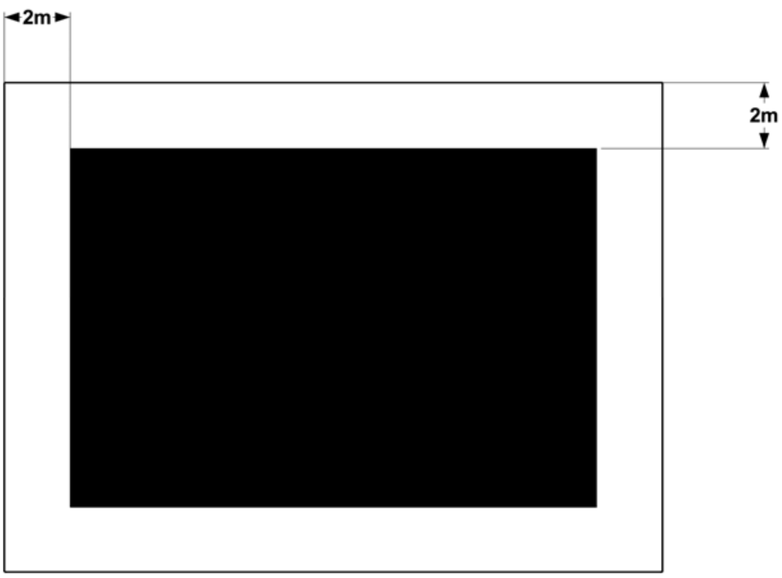

Figure 7 The issue of lot coverage by the gap around the house. With a 2 m gap, for a 300 m^2 lot area, 10 x 30 m, site coverage is 52%, for 15 x 20 m it is 59%, for a 600 m^2 lot area, 15 x 40 m, site coverage is 66%. This narrow gap alone can take up 34-48% of the lot.

Figure 8 An aerial view of a cul-de-sac off Meacher Street, Mount Druitt NSW, subdivided in the late 1990s.

Figure 9 The street scene in a cul-de-sac off Meacher Street, Mount Druitt NSW. Note the dominance of the garage doors.

Figure 10 An aerial view of part of the Perth suburb of Spearwood WA, constructed in the 2000s. It is on the opposite side of the main road from the example shown on Figure 4.

Figure 11 Street scene in part of the Perth suburb of Spearwood WA from the 2000s. Note the dominance of large paved areas and wide garage doors.

Figure 12 An aerial view of part of Springfield Lakes QLD completed in 2002.

Figure 13 The side and rear of a dwelling in Springfield Lakes QLD. Note the smallness of the backyard and meagre provision of windows. Note also the unsightly townscape and unusable grassed area.

Damage to the local ecology and microclimate

The domestic backyard has a function and importance that goes well beyond the interests of the individual household. In aggregate, it helps to create a residential area that is landscape dominated, bringing with it ecological climatic and aesthetic advantages. It is not just a matter of personal taste, such as style and decoration, much less a consumer good, such as home entertainment or a washing machine. The presence of private open space in aggregate brings significant advantages to the community as a whole.

The statistic that most clearly differentiates the form of newer Australian suburb from the older one is the larger proportion of the land area that is occupied by the dwellings. When taken together with patios, verandas and pergolas, and with the carriageways and driveways, the greater part, in some cases nearly all, of the land area is treeless and covered by impervious surfaces. Aside from the front lawns, only a small residue is permeable and planted. The damaging affect this has on the local ecology and microclimate is a problem for the whole community, not just the individual residents.

Lack of trees

Trees need space to grow both for the canopy and, most importantly, the roots. Structural damage to buildings by roots needs to be avoided. The narrow dimensions of the space around the more recent dwellings will lead to a substantial reduction in tree cover in perpetuity, as there will be no room for trees to grow at the sides and backs of the houses.

Within some of the recent developments studied, small areas of bush land have been retained and some have newly planted street trees. While the areas of bush land are welcome, they do not compensate for the lack of trees amongst the houses. For the beneficial effects to be achieved overall, a reasonably uniform distribution is required. The street trees were small at the time of writing, as the developments studied were still fairly new. If they grow to a significant height, they will provide useful shade and enclosure of space. Where they remain small, these benefits will not occur. However, even where the street trees grow to a significant size, this will still not create the degree of tree coverage found in the older suburbs.

Lack of natural drainage

The reduction in the size of planted areas to the sides and rear of the dwelling is not just a matter of fewer trees. It represents a loss of vegetation in general and its replacement by contiguous paved and built areas. There is, consequently, less permeable surface area to absorb rainfall. In aggregate, this increases storm water run-off, a matter that has serious implications. The most direct consequence is the increase in cost arising from expenditure on concrete storm drains, not just for the development itself but also for other communities “downstream” of it. It also represents a loss of water that could have been used to support local planting and so encourage biodiversity. A number of American studies (McPherson *et al*, 2005) have revealed the contribution of urban trees to the reduction of storm water run-off and the financial benefits that accrue from this. This is an issue that is particularly important for the Australian climate where long dry spells can be punctuated with episodes of heavy rainfall. Moreover, it is not helping moves to establish patterns of sustainable drainage whereby water is collected by local swales and ponds. Water sensitive urban design, as it has become known, not only brings financial and ecological advantages but can also be used to enhance the aesthetic appeal of residential schemes.

Reduced carbon sequestration and pollutant removal

One of the advantages of the planted areas created by contiguous backyards is sequestration of carbon dioxide, and various other pollutants, from the atmosphere. Although most, but not all, of the recent examples described in this paper have front lawns, the drastic reduction in the contiguous planted areas to the rear, and their replacement by buildings and hard landscaping, will reduce carbon sequestration just when and where it is most needed. This role of urban vegetation has been the subject of a number of scientific studies. For example, Nowak and Crane (2002) have demonstrated the effectiveness of American urban trees in the sequestration of carbon in American cities. Golubiewski (2006) has demonstrated the role of lawn grass in the same process and shown how its efficacy exceeds that of native and agricultural grasslands. The same findings have been obtained by Pouyat, Yesilonis and Nowak (2006). McPherson *et al* (2005), in their studies of urban trees in American cities, found not only significant carbon sequestration but also an important reduction in ozone, nitrogen dioxide, sulphur dioxide and small particulates, both through the direct absorption by leaves and by the avoidance of pollution through energy reduction in the home. Turning to Australia, Coutts, Beringer and Tapper (2007) have shown how urban vegetation in Melbourne plays an important role in mitigating the carbon emissions in that city. The studies by the City Council in Brisbane (Plant, 2006) found that, in 2000, Brisbane's residential tree cover was estimated to be absorbing the equivalent amount of carbon dioxide emitted by 30,000 cars per year.

Lack of natural climate control

The importance of trees, plants and water for a beneficent microclimate, especially in the hot and dry circumstances of Australia, was explained earlier. For example, studies by the City Council in Brisbane (Plant, 2006) found that Brisbane's residential tree cover cooled surface temperatures in the relatively mild month of October 1999 by up to 5 degrees Celsius. When applying the effects of tree shade on the eastern and western sides of a single-storey, 3 star energy-rated home, energy savings of up to 50% per annum could be achieved. For the more recent suburbs, the reduction in tree cover and absorption of water coupled with the increased absorption of solar heat and its expulsion into the narrow confines between the dwellings will have a notably adverse effect. What is so worrying is that what is happening here is going in exactly the opposite direction as to what would be expected in a hot dry climate. The lack of tree cover will greatly increase the heat absorption by the buildings.

The dwellings in the newer suburbs are generally of deep-plan layout with small windows. Their design relies on air conditioning for them to be habitable. However, even if they had been designed for natural ventilation, the reduction in width between the dwellings would make this very difficult, especially in those parts of Australia with subtropical climates. A study by Lee Su San (1998) of suburban development in the Douglas area of Townsville revealed that the narrowness of the gaps between the houses prevented airflow around them, creating a "heat island effect". Her studies of actual buildings confirmed previous experimental results from wind-tunnel tests with models of buildings (Lee, Hussain and Soliman, 1980). For single-storey dwellings with a comparatively narrow gap between them, the prevailing winds skim over the roofs without exerting air pressure within the gaps to force natural ventilation. Natural ventilation of houses from the wind is increased if the buildings are two, rather than one, storey high. The problem was exacerbated by the exhaust from the air conditioners and the dark coloured roofs which absorbed, rather than reflected, the heat. The use of impervious sheet metal fencing, rather than, open link fencing, was also a factor in reducing airflow. These findings were confirmed by numerous complaints from the residents (Clark, 2006).

Overall, in the conditions of the Australian summer, a vicious circle is created. The houses absorb more heat because of their deep-plan form and large roof area. This heat is expelled by the air conditioning systems. It is not dispersed by prevailing winds and further increases the temperature around the house. This causes the heat to be re-absorbed by the structure, making even more work for the air conditioners. The gaps between the houses are not only made insufferably hot but are also affected by the noise of the air conditioners rendering the environment of the side and rear spaces, however they are planted and decorated, unpleasant. The overall effect is an increase in electricity consumption for the household at a time when more emphasis on the prudent conservation of energy is required.

Lack of biodiversity

The minimisation, and even elimination, of planted areas also has serious consequences for biodiversity in general. Once lost, species may take many decades to re-establish themselves or may disappear from the area forever. The interconnecting area of soft landscaping created by adjoining backyards hosts a high degree of biodiversity. The density and variety of the planting in a domestic garden is something that is not found elsewhere. For example farming monocultures, and even playing fields, have very limited biodiversity in comparison. Authors have remarked upon the number of plant species to be found in back gardens in European cities (Gilbert, 1991; Pysek, 1989). From studies of English gardens, Gilbert (1991) draws attention to the variety of vegetation to be found not only in planted beds but also in lawns, ponds and on walls. He also describes the variety of the associated fauna which includes insects and other small creatures. Jennifer Owen has argued strongly (Owen, J. & D. F., 1975) for the high degree of biodiversity in the English garden on the basis of her studies of insect life. Cannon (1999), taking an international perspective, has drawn attention to the importance of the private garden for bird life.

Turning to Australia, the same situation is to be found. Daniels and Kirkpatrick (2006) have drawn attention to the important role played by back gardens in the conservation of bird species in Hobart.

The studies by Taylor, Leach and Smith (2006) of individual home gardens in the city of Adelaide showed them to be astonishingly diverse, with more than 300 plant species found growing on some suburban housing blocks. Moroney and Jones (2006) have drawn attention to how decreasing lot sizes in Southeast Queensland have shown a reduction in biodiversity. Such losses also have a wider cultural and educational significance which is often not readily appreciated.

Damage to the amenity of the dwelling

In addition to the benefits to the community as a whole, the backyard provides important benefits to the individual household. The most important ones, those relating to outlook and ventilation, apply even if the occupants never venture out into their backyard. The issue for the use of space surrounding the dwelling is not just its area but also its shape and degree of surveillance. The problem in the newer suburbs is that the space is long and narrow thus limiting the range of facilities and activities that can be accommodated within it. In the worst examples, the windows are small and few in number, making it difficult for people inside to see what is happening in the yard and for those in the backyard to connect with activities in the house.

Lack of outlook

One of the most important roles of private open space around the home is to provide a pleasant outlook from inside the dwelling. For the examples from the more recent suburbs, the single-storey houses often have an outlook on to a high fence to the sides and rear, perhaps only 2 m away. There is often a lack of windows as there is little for them to look out on to. Two or more storeys can increase the outlook for the upper floors but the problem still remains for the ground floor. The degree of enjoyment of the house by its occupants is consequently reduced. Studies in medical settings (Ulrich, 1981, 1984; Moore, 1981) have shown that a pleasant view and natural sunlight can have beneficial effect on personal health and well-being. This is an important quality of life issue.

Reduction in outdoor facilities

The majority of the backyards studied in the research would not be able to accommodate a significant in-ground swimming pool. Barbecues would be possible but the space is limited and large social gatherings would be very restricted, as would other outdoor dining events. Home food production would not be possible and accommodating large external rainwater tanks and home composters would be very difficult. For many there is no room for a Hill’s Hoist and the ability to dry laundry in the open air would be very limited.

Little scope for children’s play outdoors

In many of the examples studied, children would be the principal sufferers as there is little space for them to run around and make noise without disturbing others while, at the same time, remaining in a secure environment with a responsible adult keeping watch from inside the house. This is especially important for very young children. A study by Flinders University (Spurrier, Magarey, Golley, Curnow and Sawyer, 2008) has pointed to less physical activity where children lack access to significant backyards. This was not compensated for by public open space and playgrounds. The authors saw this as leading to sedentary lifestyles and childhood obesity.

The role of public and semi-public open space

It is important to distinguish the role of the backyard from those of the front yard and the public park. They all share the ability to provide biodiversity, aesthetic pleasure and a beneficial microclimate. The front garden can certainly have an important role (Hall, 2006). The public park has an even more important one, particularly because of the larger-scale recreational opportunities it affords. In Australia, it can provide the location for gatherings of a significant number of friends and family for barbecues. However, the front garden is semi-private (or semi-public) and the park is completely public. They cannot offer the same privacy and degree of security as the backyard. This is particularly important as far as very young children are concerned. In addition, a public park cannot provide ventilation and outlook for all the houses. Although essential for urban amenity, it cannot replace the backyard in respect of the environmental functions discussed above.

In summary, the green space around all dwellings has important social and environmental functions and is an essential component of sustainable living. Urban amenity is not just a matter of provision of public parks but how private planted areas are integrated within the urban fabric.

Is urban consolidation the problem?

A common response to these figures is that they must be the result of smaller lot sizes, probably resulting from planning strategies directed at urban consolidation. Writers such as Patrick Troy (1996) have warned of the adverse consequences of such policies. Both urban consolidation policies and market pressures contribute to increases in residential densities and smaller lot sizes in parts of Australian cities. This is happening to a greater extent than in the US where densities in the extreme outer suburbs remain low and lot sizes continue to increase. However, the Australian situation has a long way to go before it even approaches the suburban densities common in Europe. Is, then, real urban consolidation actually occurring in Australia to any significant extent? At the time of writing, large expanses of low-density housing are still under construction on, and beyond, the edges of most Australian cities. It might be countered that the effects of newer planning policies at State level have yet to be seen on the ground. However, an increase in density to, say, 15 dph, as is now the policy in some parts of the country, is still very low by European standards and, even in the Australian context, hardly represents high-density urban form.

There is, indeed, a trend to smaller lot sizes in Australia but a closer examination of the data reveals that this not the cause of the phenomenon. What the Tables show, for the examples studied, is that where the lot area is large so is the house footprint. Note that the lot-size distribution for the new section of Spearwood WA is, at around 600 m^2, almost identical to that for the older "Queenslanders" at Camp Hill QLD. Statistics at the national level (ABS, 2005) show a substantial rise in the floor area of new houses since the 1980s. From a figure of 162.2 m^2 in 1984-5, by 2003-4 the average floor area had risen to 227.6 m^2, an increase of 40%. The increase in the ten-year period from 1993-4 to 2003-4 was just over 20%. The average lot area also declined over the same ten-year period, from 802 m^2 in 1993-4 to 735 m^2 in 2003-4 (ABS, 2004). However, this is still a large figure and the evidence suggests that it is the increase in the dwelling area, rather than the decrease in the lot area, that has driving the diminution of the backyard.

Even if urban consolidation did become a reality, would this necessitate a reduction in size, or even elimination of, private space around the dwelling? What the European, particularly the British, experience shows, is that there is no necessary connection between higher densities and very small or non-existent backyards. Letchworth Garden City in Hertfordshire was the world's first planned "garden city" and its landscape-dominated form and neo-vernacular architecture became a model that was influential and widely copied. The actual density is much higher than visitors usually imagine when they first encounter its landscape-dominated townscape. Gross densities can be as high as 20 dph and net residential densities can range from 22 dph to 35 dph. Even allowing for the fact that the dwellings are all two-storey, dwelling footprints are very small in comparison to Australia. In consequence, the house footprint occupies less than 30% of the lot area, and often as little as 12% (Hall, 2010).

Recent British central government policy has required a minimum net density of 30 dph. However, new suburban housing schemes without private open space cannot be found because they are not allowed. What is notable about the British situation is that at densities in the range 30-55 dph, many times those in the newer Australian suburbs, back-to-back distances and rear garden sizes are greater than in many of the older Australian suburbs. With good urban design and strong planning intervention, front-to-front distances can be reduced and houses can have more storeys giving more floor area for the same footprint. Houses do not need to be bigger if lots are smaller. Backyards of 100-150 m^2 can be provided at densities up to 40 dph, even 60 dph (Hall, 2007b). A house and garden form is maintained even when the street space is definitely urban in character.

The diminution of the Australian backyard is not, therefore, a necessary consequence of higher densities. On the contrary, what is so remarkable about the phenomenon is at its worst in the extreme outer suburbs where densities are at their lowest. Even where plots are very large, as in the Spearwood example, the very large lots are completely covered by very large houses. The problem occurs in both low and moderately high-density areas.

The role of local planning regulations

Given the clear-cut spatial and temporal characteristics of the phenomenon described, what has been the role of local planning regulations in the process of change? Did they require it or merely allow it? The parameters that have changed, for example lot coverage and distances between dwellings and lot boundaries are the very quantities that such regulations normally deal with.

What is remarkable is how the diminution of the size of the backyard has been occurring over the whole of Australia. This is despite a significant variation in both the scope and details of plans and regulatory instruments across the many planning authorities. As the problem appears to be national in its scope, the first place to look for answers is the guidance given by the federal government. Between 1977 and 1995 it showed concern with how residential development could exhibit affordability and amenity, resulting in several versions of the *Australian Model Code for Residential Development* (AMCORD). The last was AMCORD 1995 (Green Street Joint Venture, 1995). This opted for a private open space provision of a minimum of 20% of the site area. However, an area of space in aggregate may not equate to the actual area of a backyard as commonly understood. As explained by Figure 5, a narrow strip around a house can amount to 34-48% of the lot. The provisions therefore included an additional minimum dimension for a useful backyard, the *principal area* of 25 m^2. The minimum linear dimensions were 4 m x 4 m. What is remarkable is not only how small these sizes are compared with the dimensions of older suburban yards given in Table 1, but also that they are smaller than the yard sizes for the more recent suburban examples given in Table 3. No empirical justification was offered for these figures.

AMCORD was only advisory and there has been no equivalent initiative at federal level since. Requirements for residential private open space are largely enforced through building and development codes by state governments and local councils. There are certain parameters that nearly all codes, where they exist, specify, no matter how simple they are. Most codes specify maximum requirements for lot coverage as a total percentage of lot area. A maximum figure of 50% is very common. As is demonstrated by Figure 5 and the data in the Tables, this is insufficient to prevent the erosion of the backyard. To maintain a useful size of backyard, the upper limit would need to be at most 40%, ideally 30%. In addition, there is normally a minimum distance required between the edge of a building and the edge of the lot. At the sides and rear boundaries, this minimum distance is usually just 1-2 m. To maintain a proper size and shape of backyard of the dimension set out in Table 1, a rear setback of at least 8-10 m would be necessary. In addition, the codes normally require that a dwelling must be set back a certain distance from the lot boundary adjoining the road reservation, typically 4-6m. The requirement for a large amount of space to the front of dwellings is a tradition that is maintained in the newer suburbs and is a major contributor to low residential densities. Consequently, the space at the front now often exceeds that at the back.

New South Wales

Mount Druitt lies within the Blacktown LGA. During the 1980s and 1990s, there were no minimum requirements for private open space provision and therefore nothing to prevent the situation in the example off Meacher Street described. In 2006, the Council introduced the Blacktown Development Control Plan (Blacktown 2006) which specified a minimum private open space provision of 80 m^2 behind the building line containing a minimum space of 6m x 4m. Although this step could be seen as correcting the previous situation, its content is not very generous compared to the backyard sizes in the older suburbs.

Queensland

Except where varied by an approved local plan, all new housing in Queensland is subject to the Queensland Development Code (Queensland, 2007). The Code specifies minimum building clearances around the boundaries of a lot. These vary according to circumstance but in no case exceed 2 m. The maximum site coverage permitted for the dwelling footprint is 50%. For lots under 450 m^2 in area, an outdoor space is required at the rear of the dwelling with a minimum area of 16 m^2 and minimum dimensions of 4 m x 4 m, reflecting the AMCORD principal area. What is interesting here is, firstly, that the idea that it is proper to for a Code to specify such space is conceded and, secondly, how small it is. For lots greater in area than 450 m^2 no minimum dimensions for a rear yard are specified at all.

The Springfield Lakes example lies just over the Brisbane City boundary within the Ipswich City LGA. Its design was regulated by the *Springfield Lakes Design Manual* (Ipswich, 1997) which was drawn up jointly by the Council and the developers. Its expectation is “predominately private yards” but the lot coverage maximum is given as 50-60%, in excess of the Queensland code. Later in the manual there is a specific requirement for provision for “subtropical outdoor living”: an “indoor/ outdoor roofed room accessible from the main living area and exposed to natural ventilation and winter sun”. However, the minimum area is only 25 m^2, or 12 m^2 if a deck, with no requirement for planting.

Western Australia
Provisions for the control of suburban form in Western Australia arguably represent some of the highest standards in Australia to date. Moreover, nearly all the current urban expansion of the greater Perth region is now in the form of master-planned estates. Western Australia's design policy, *Liveable Neighbourhoods* (WPAC, 2004) was, and possibly still is, the only one in the country that has actually tried to ensure that all urban form is laid out in accordance with a comprehensive design vision. It is now compulsory for all new development in Western Australia to comply with the code. However, it does not regulate the design of dwellings and the disposition within the lot. These matters are covered by the separate *Residential Design Codes of Western Australia* (WPAC, 2002) known as the R-Codes.

The R-Codes recognise the importance of private open space around the dwelling. The open space referred to includes that at the front and sides of the dwelling as well as that at the rear and so, sensibly, the codes require the provision of an *outdoor living area* within it. They do not say explicitly that the outdoor living area should be to the rear, or in another location where the users would enjoy privacy. The objectives are consistent with large backyards but, as with other examples discussed, the problem comes not with the general intentions but with the actual quantities specified. Minimum areas of outdoor space around the house range from $16m^2$, for lots up to $200m^2$, to $36m^2$, for lots up to $580m^2$. Above $580m^2$ no minimum value is specified. Unfortunately, as we have seen at Spearwood WA, the lots over $600m^2$ now present some of the most extreme cases and are direly in need of a minimum standard.

Minimum site coverages for the outdoor living space range from 45% to 50%. However, we have already seen a narrow strip around the house can easily absorb both this proportion and also the minimum area figures of 24-36 m^2. A specification of minimum width and length is, therefore, essential. In this case, it is only 4m x 4m, possibly taking its cue from the AMCORD provisions. Although the sentiments in the R-Codes are very positive, their translation into quantities is minimalist.

Conclusions
Up until the 1980s, the physical form of the Australian suburb was characterised by detached houses taking up a third, or less, of the lot and facilitating a large backyards of $150m^2$ to $400m^2$. Such spaces accommodate a wide range of activities but their role is not confined to the individual lot. Planted areas adjacent to dwellings not only facilitate a pleasant outlook for the occupants but also provide shade from the sun and assist the natural ventilation of the house. They also provide a secure play area for young children and space for social facilities for all ages. The backyards coalesce to form contiguous planted areas to the rear of properties which are important for biodiversity, sustainable drainage, an equable microclimate and the sequestration of carbon dioxide and other pollutants.

During the 1990s, the physical form of new suburban development in Australia changed dramatically. Houses with large backyards ceased to be built. Suburban form since then has been characterised by dwellings which cover at least 40% of the lot. Such houses have a deep or square plan with minimum wall length, few windows, an integral garage, and often single-storey. These trends have resulted in a diminution of the backyard in both shape and total area. This has reduced the amenity of the property in terms of outlook from the dwelling and facilities for outdoor recreation around the home, especially for young children. However, the disadvantages go well beyond the lifestyles of the occupants. There is a loss of biodiversity and an increase in run-off of storm water. The microclimate becomes hotter and this, in turn, requires more air-conditioning and increased energy use. Moreover, it represents a permanent change in building form that cannot be corrected later.

There is no evidence that this trend has been brought about directly by policies of urban consolidation. It is to be found in lower-density outer suburbs located a considerable distance from city centres. Although lot areas have become smaller overall, the phenomenon is to be found at all lot sizes. Local policies and planning regulations have not explicitly required small backyards. The provisions for private open space in development codes are minima not maxima. Had developers, property owners or builders, or any other parties involved, wished to continue to provide backyards on the scale seen before the 1990s, there was nothing in the codes to prevent them from doing so. However, whatever may have been the intention behind the codes, there was nothing in them to prevent the reduction in the size of private open space that has occurred. They have contained no provisions that would have retained the large backyards.

The environmental disadvantages of the reduction in private open space have been set out. However, this should not be seen as then end of the story. The issue begs many questions for both further research and political action. It is a topic on which, hopefully, future enquiry and debate can be focussed with advantage.

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Table 1 - Dimensions of selected examples from older Australian suburbs

		Caringbah NSW 1900s	Kew East VIC 1930s	Camp Hill QLD 1940s	Jannali NSW 1950s	Hebersham NSW 1980s	Spearwood WA 1980s
distance from city centre	km	21	9	5.7	22	38	17
net density	dph	8	11.6	11	13.4	13	9.3
typical front-to-front distance	m	35	29	30	32	34	33
average lot area	m^2	1120	833	628	560	579	670
net average dwelling footprint	m^2	207	215	165	130	132	196
average net lot coverage	%	22	26	27	23	23	30
gross average dwelling footprint	m^2	283	268	181	198	201	249
average gross lot coverage	%	30	33	29	34	35	38
average backyard area	m^2	419	311	268	220	169	202
average rear setback	m	17	19	29	23	12	14

Table 2 - Distribution of backyard sizes in the examples of older Australian suburbs

	Caringbah NSW 1900s	Kew East VIC 1930s	Camp Hill QLD 1940s	Jannali NSW 1950s	Hebersham NSW 1980s	Spearwood WA 1980s
m^2	%	%	%	%	%	%
0-49	2	0	0	0	0	9
50-99	4	4	7	0	11	17
100-149	6	7	4	18	32	4
150-199	4	8	11	21	21	22
200-249	6	12	22	34	32	13
250-299	6	23	19	18	4	4
300-349	2	12	19	3	0	22
350-399	2	8	4	3	0	9
400-449	10	12	11	0	0	0
450-499	16	8	4	0	0	0
500-549	18	7	0	3	0	0
550-599	18	0	0	0	0	0
600-649	6	0	0	0	0	0

Table 3 - Dimensions of recent examples from outer suburbs

		Springfield Lakes QLD	Meadow Heights VIC	Mount Druitt NSW Rooty Hill	Mount Druitt NSW Meacher St	Blakeview SA	Smithfield Plains SA 2000s	Spearwood WA
distance from city centre	km	23	18	38	38	30	30	17
net density	dph	16	19	19	18	16	22	14
typical front-to-front distance	m	23	24	25	23	25	23	24
average lot area	m^2	556	393	378	411	492	352	569
average net dwelling footprint	m^2	231	163	146	171	212	144	281
average net lot coverage	%	44	41	39	42	44	42	50
average gross dwelling footprint	m^2	239	189	169	209	242	155	314
average gross lot coverage	%	46	46	45	52	50	46	56
average backyard area	m^2	113	99	74	74	111	84	46
average rear setback	m	6	7	5	4	7	6	4

Table 4 - Distribution of backyard sizes in the recent examples from outer suburbs

	Springfield Lakes QLD	Meadow Heights VIC	Mount Druitt NSW Rooty Hill	Mount Druitt NSW Meacher St	Blakeview SA	Smithfield Plains SA	Spearwood WA
m^2	%	%	%	%	%	%	%
0-49	18	14	30	29	25	25	50
50-99	39	32	48	58	17	45	47
100-149	21	43	16	6	26	15	3
150-199	13	7	6	3	24	8	0
200-249	4	4	0	0	7	3	0
250-299	2	0	0	3	0	5	0
300-349	2	0	0	0	0	0	0

ENERGY SAVING BENEFITS OF SHADE TREES IN RELATION TO WATER USE

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Project overview

Increasing the number of urban trees, and appropriately positioning those trees in relation to buildings and impervious surfaces, is a simple but effective strategy for urban climate change adaptation / mitigation to reduce energy consumption, greenhouse gas emissions whilst improving human thermal comfort and reducing human heat stress. To better communicate and value the importance of urban trees it is necessary to directly quantify these benefits, and to understand the properties and processes that influence the magnitude of these benefits. This project is being funded by Nursery and Garden Industry Australia (NGIA) providing support for two Masters students to:

- Directly quantify the dollar benefit deciduous and evergreen trees provide through reduced energy used for the heating and cooling of buildings.
- Directly quantify tree water use to provide an indication of possible water costs.
- Raise awareness of the thermal and energy benefits urban trees provide in the built environment through an educational installation at Melbourne Flower and Garden 2011.

Background

Urban trees provide many important social and environmental services such as: shading and cooling of walkways and buildings, mental health and well-being, biodiversity habitat and conservation, carbon sequestration, and atmospheric pollution filter (Bolund and Hunhammar, 1999; Nowak and Crane, 2002; Pataki et al., 2006). Only a few desktop studies have assessed the environmental benefits of urban trees in Australia (Brack, 2002; Brindal and Stringer, 2009; Killicoat et al., 2002; Moore, 2007; Moore, 2009; Plant, 2006). Better protection, planning and management of urban trees is necessary to ensure that Australian cities are best able to adapt to climate change whilst enhancing their liveability (Beeton et al., 2006; Committee for Melbourne, 2008). To communicate the importance of urban trees in Australian urban centres, it is necessary to quantify some of the more important ecosystem services they provide, and to understand the 'properties and processes' involved. This will provide city managers, urban planners and developers throughout Australia with a scientific basis to maintain and enhance the urban forest.

Internationally, there has been great progress in the measurement and modeling of the carbon, climate and energy benefits of urban trees in the last 10 years (Akbari, 2002; Ca et al., 1998; McPherson et al., 1998; 2005; Nowak and Crane, 2002). Akbari et al. (1997) directly measured a 30% saving in summertime cooling energy use in a Sacramento, California home. Simpson and McPherson (1996) through simulations estimated that tree plantings around Californian homes could reduce energy used in summer cooling by up to 50%. Last year, Akbari (2009) released a "how-to" guide on planting trees in the US for energy use reduction, with expected energy saving benefits between 15 and 35%. If those same energy saving benefits could be demonstrated in Australia, urban vegetation would be taken seriously as a climate change adaptation initiative.

Fisher (2007), drawing upon international studies, estimated that shade trees in Australian cities such as Melbourne and Adelaide could save ~30 kWh per tree, therefore Melbourne's 2.4 million shade trees could save 72 million kWh per year, avoiding 86,000 t CO_2 emissions per year from coal powered electricity. Estimating the benefit of Australia's urban trees from international data is problematic. The actual benefits will vary greatly according to the climatic conditions in each Australian city, the type of tree shade (e.g. eucalypts) and the properties of the building being shaded.

In summer, the energy saving benefits of trees next to buildings will facilitate through both direct shade reduction of thermal load on the external wall surface, but also through the evaporative cooling of the air mass adjacent to the walls through foliar transpiration. In winter, the presence of tree shade can either be a negative, preventing the warming benefit of any winter sun, or it can be a positive, reducing the cooling effect of winter winds (Akbari et al., 2009).

This project will quantify the energy saving benefits of trees in a built environment whilst concurrently quantifying tree water use, thereby providing a data platform to convert both costs and benefits into a dollar value.

- Energy used for cooling or heating a building has a dollar value, and an indirect carbon cost, so this project will directly quantify the energy savings that urban trees can provide to the built environment through modified micro-climate conditions.
- Water to keep those trees alive also has a dollar value according to urban water rates and irrigation infrastructure.

This collaborative research project is funded by NGIA and involves the Melbourne School of Land and Environment, the Faculty of Engineering and the Faculty of Architecture Building and Planning at the University of Melbourne and the Monash Sustainability Institute, School of Geography and Environmental Science.

Project approach

Nursery and Garden Industry Australia has provided funding to establish and instrument three weather-board, single-room, galvanized-iron roof buildings (3.2 x 3.7 x 3.3 m) at the Burnley campus of The University of Melbourne. Each building has been equipped with a reverse-cycle air conditioner attached to a continuously logging power meter to record energy consumption.

Along the northern and western walls of two buildings (A and C) trees have been placed in large (75 L) pots that receive potable irrigation twice a week through timed drippers. Building A is flanked by nine potted *Eucalyptus sideroxylon* (Ironbark) trees, whilst building C is flanked by nine *Fraxinus excelsior aurea* (Golden Ash). These trees are placed 1.5 m from the building. Building B acts as a control with no trees, however, due to subtle differences among the three buildings each building acts as its ‘own control’ for one week in every 8 weeks by simply removing the trees.

The energy benefit of the evergreen eucalypt and the deciduous trees can be directly and simply estimated by differences in mW/h energy use in air conditioning, as each house is kept at a near constant temperature (21°C) through heating in winter, and cooling in summer. At the same time, heat flux sensors have been installed on the inside of each wall, ceiling and floor (under carpet). These are connected to a central logger in building B (DT85, Datataker™, Australia). Each heat flux sensor (Omega™ HSF-4, USA) records surface temperature (°C) and heat flux (W m^{-2}) every 30 seconds. The flux of heat into a building on a sunny day produces a positive reading, whilst heat flux out of the building is indicated by a negative reading. From this data and standard weather station information at the site (air temperature, relative humidity, rainfall, wind speed and direction, net radiation) it is possible to construct a heat balance for each building. Direct measures of building heat balance are being related to simulated estimates of building heat balances using Integrate Environmental solutions (IES™, Glasgow, Scotland) software based on input data of building properties, tree properties and climatic data.

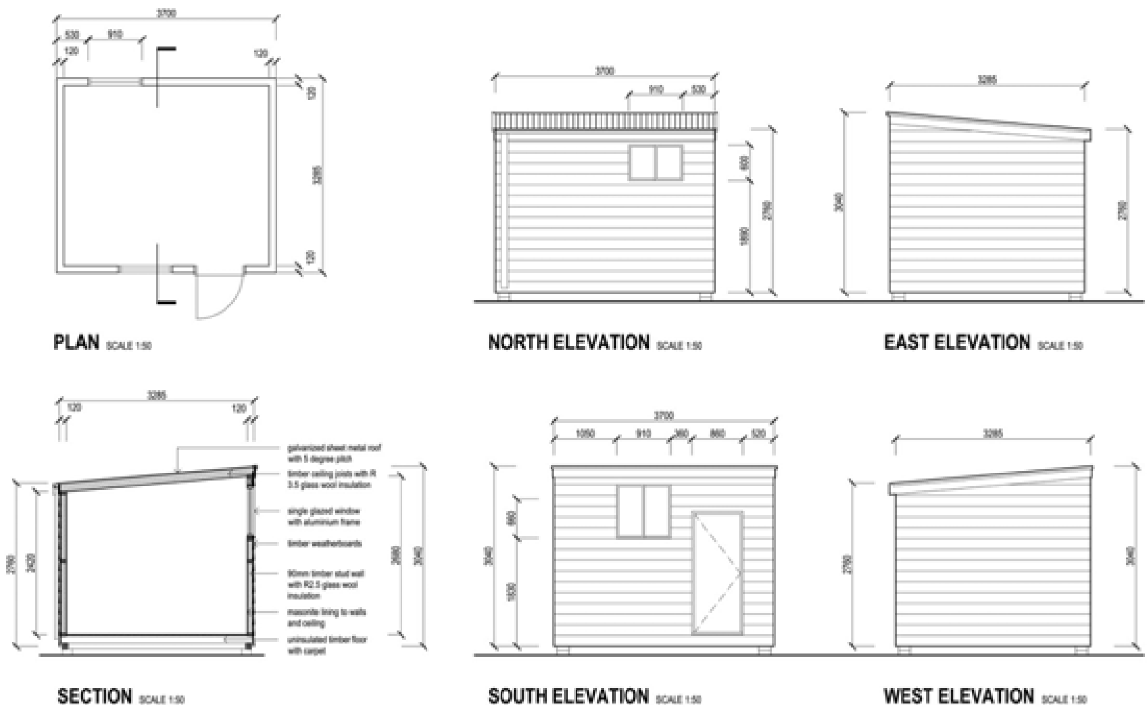

Figure 1. Dimensions and properties of weather-board, single-room buildings installed at the Burnley campus, The University of Melbourne (courtesy of Anthony Dawkin, ABP, UniMelb).

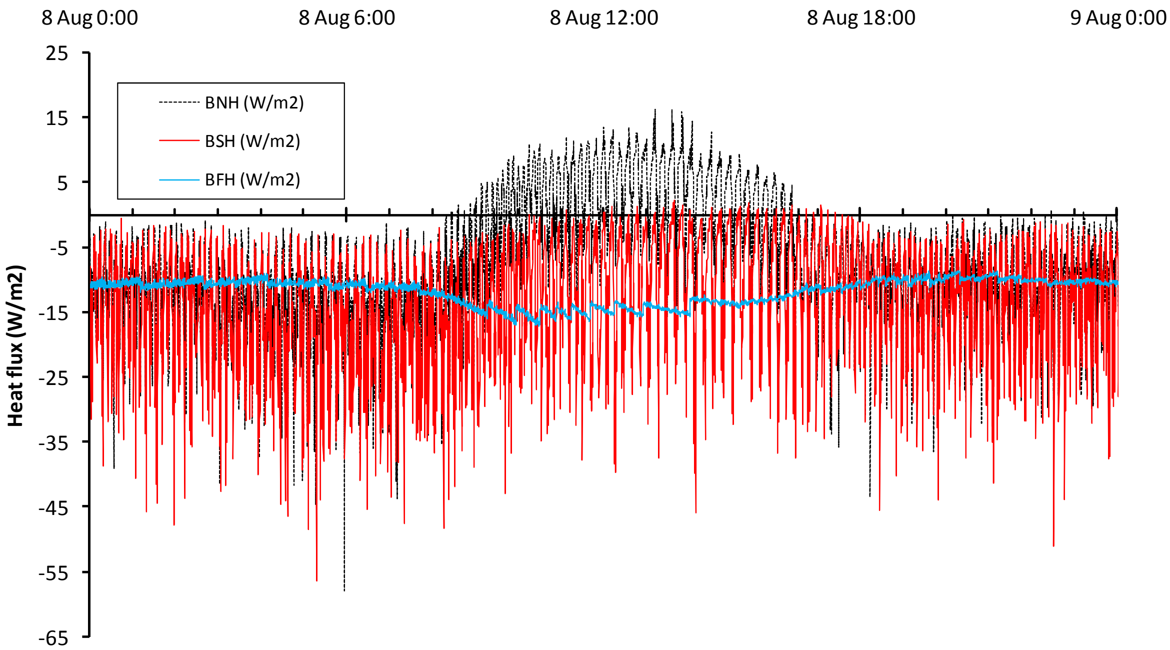

Figure 2. Heat flux (W m-2) over a 24 h period in winter 2010 through the north wall (BNH), south wall (BSH) and the floor (BFH) of building B, at the Burnley campus, The University of Melbourne. Note positive heat gain through the north wall in the middle of the day, and constant heat loss through the south wall and floor at all times. Large variation in wall heat flux is due to the pulse-operation of the air conditioner.

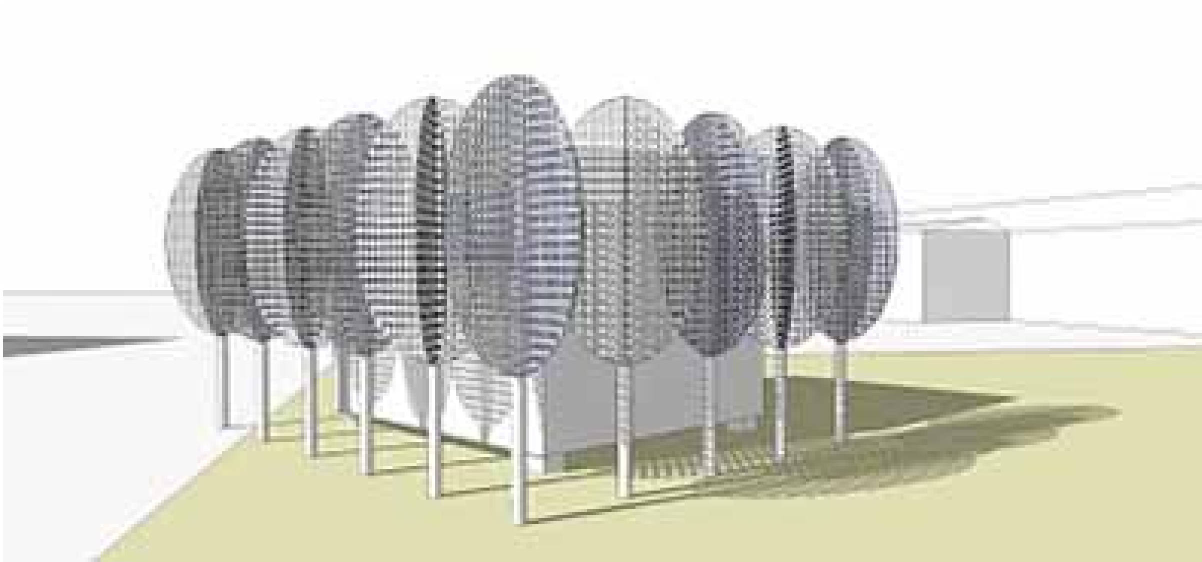

Figure 3. IES simulation of 50% canopy shade trees on the northern and western walls of a building and the shade cast from sun's zenith. (courtesy of Anthony Dawkin, ABP, UniMelb)

At the same time, direct water use by these trees will be measured using two methods. By keeping the trees in large pots (75 L), water use can be measured from the change in the mass of the potted tree in between rainfall or irrigation events. One *E. sideroxylon* and one *F. excelsior aurea* tree are constantly seated on two 300 kg platform load cells linked to a laptop PC with mass logged every 60 seconds. A 3 cm layer of scoria gravel on the pot surface minimises evaporation from the pot surface. As an alternative, leaf level measurements of stomatal leaf conductance (transpiration) are being made seasonally using an infra-red gas analyser (LICOR™ 6400, USA). Branch diameter to leaf area allometrics will be established through destructive harvests of two *E. sideroxylon* and two *F. excelsior aurea* trees in mid-summer and then related to repeated and detailed branch diameter measurements to accurately estimate the total leaf area (m^2) of each tree over time. From leaf level transpiration measurements (mmol m^{-2} s^{-1}) it will be possible to estimate transpiration in mm $tree^{-1}$ d^{-1}.

Project future

This project commenced in July 2010 and is yet to provide sufficient temporal data from which to present initial results and draw any conclusions. The project will run for one year, but provides the basis and research infrastructure to investigate many research questions that relate to the use of urban green infrastructure. For example, in addition to quantifying the energy saving benefits of different urban shade trees, this research infrastructure can be equally applied to investigations of green roofs, green walls and even white roofs. Furthermore, this research framework can investigate issues of urban green infrastructure with regards to building energy use, thermal load, plant water use, micro-climate, rainfall retardation and run-off quality.

This study provides a powerful educational and awareness-raising resource that public and policy makers can easily understand because it provides a strong visual, three-dimensional demonstration. At the same time, this research is advancing the scientific skills and capacity of urban tree researchers in Australia, by providing a multi-disciplinary and collaborative research program that should deliver more than the individual contributors could alone.

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SEEING THE FOREST AND THE TREES IN CANBERRA USING AN AUDIT AND INVENTORY APPROACH

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Overview

Between November 2009 and May 2010 approximately 490,000 of Canberra's urban trees were assessed and the findings recorded, using GPS technology, into the city's Integrated Asset Management (IAMS) database. Of this total number, 460,000 trees were assessed using a 'rapid audit windshield approach' over a ten week period.

This paper will discuss the relative merits and complementary roles that these two assessment approaches play in understanding and developing a strategic plan for the management of Canberra's unique urban forest with consideration to the trees' current and predicted future condition.

Canberra's urban forest

The ACT Government manages more than 640,000 urban trees in streets and parks, making it one of the largest urban forests managed by a single jurisdiction in the world. The first urban plantings started in the 1920's and continue today, giving an age range for the trees from new to 95 years old. Canberra's urban forest is dynamic and still rapidly expanding. In the past three years alone, 18,000 trees have been planted in the new suburbs.

Knowledge of Canberra's social and political development provides a useful context to understanding Canberra's urban forest. In 1901 Joseph Maiden from the Royal Society in NSW proclaimed '*the whole of the Federal territory can be looked upon somewhat in the light of a gigantic park, the streets and buildings to be inserted as details*...'. He went on to say '*we have no grand Arboretum in Australia, and the foundation of the Federal City given us the opportunity of establishing one…*'. There was great idealism with the creation of the 'Federal Capital' and anyone visiting the site may have needed optimism. The site of Canberra was predominantly grassland and in the 1920s it was either cold and windy or dry and dusty. One of the first tree plantings for the new city was in 'Haig Park', which is essentially a parkland of exotic, mainly coniferous trees. It was constructed as a windbreak and marked the formal northern boundary of the city.

Tree planting took place on an industrial scale which coincided with the construction of the city. In the six suburbs that make up the original part of the region known as the Inner North, over a million trees and tall shrubs were planted in a four year period in the 1920s[1]. Canberra has experienced three planting phases on this industrial scale. The first was at the inception of the city in the 1920s, the second started in the Menzies era in the 1950s with the construction of Lake Burley Griffin and the third in the 1970s with the expansion of the city and construction of two satellite regions, Woden-Weston and Belconnen. These two regions alone contain 230,763 trees.

In 1996 the ACT Government commissioned the Fenner School of Environment and Society, led by Associate Professor Cris Brack, to survey Canberra's trees and develop a modelling system for their management. The output of this research was the Decision Information System for Modelling Urban Trees (DISMUT). This research estimated that up to two-thirds of Canberra's urban trees would decline in the coming 20-30 years.

The following chart shows the numbers of trees planted since the 1920s. You will note the scale of the tree planting from the 1950s to the 1980s. The majority of these trees were *Eucalyptus sp*, some of which are not performing well as street trees as a combination of species choice, growing conditions and/or maintenance practices.

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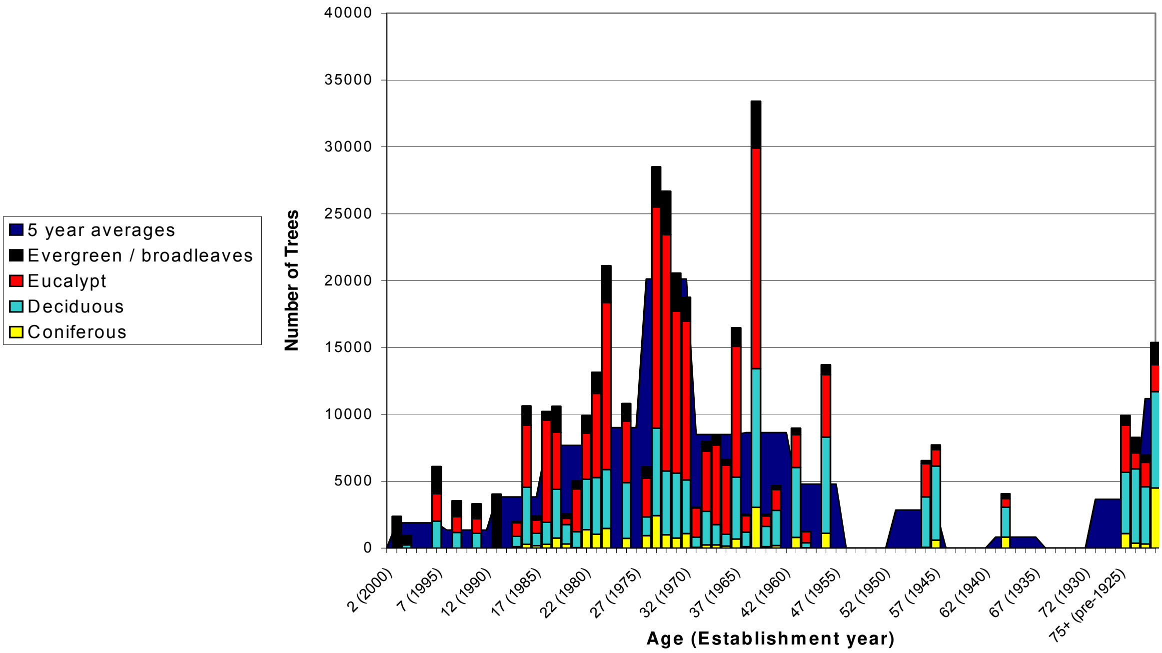
[1] Taylor, K, Canberra, City in the Landscape, 2006,



One of the primary reasons for this decline is the simultaneous ageing of the trees from the two earlier planting periods, the 1920s and the 1950s and a drying climate. Trees in the original plantings under the direction of Charles Weston, Officer-in-Charge Afforestation 1913-1926, were predominantly exotic and trees from this group have an expected safe and useful life of 80 plus years. The tree species from the 1950s to the 70s were predominantly native and have a shorter 'safe and useful' life. These two large groups of trees are maturing simultaneously. Following on from the ANU's work, the ACT Government recognised that a plan was needed to manage the issue of declining trees with consideration to social, economic and environmental issues. This resulted in 2008 with the establishment of the Urban Forest Renewal Program (UFRP).

The UFRP aimed to '*sustain and enhance Canberra's urban forest for future generations*.'

Its strategic plan identified five guiding principles for urban forest management, namely:

- Maintenance of the contribution of the urban forest to Canberra's distinctive landscape setting and character.
- Reduction of risks to people and property from declining and failing trees.
- Optimisation of the use and care of trees, with tree selection based on survival prospects under climate change scenarios and on avoidance of species with the potential to become pest plants.
- Improvement and maintenance of environmental, social and economic benefits.
- A flexible approach should be taken to tree renewal.

The first phase, 2009-2013, the UFRP had the following four key outputs*:

- A condition assessment of Canberra's urban forest.
- Introduction of a programmed preventative maintenance (cyclical) program.
- Strategic replanting and review into trees suitable for Canberra.
- An informed and supportive community.

* The Urban Forest Renewal Program has been under Review by the Commissioner of Sustainability and the Environment for the ACT since November 2009. The outcome of this review should be completed in September 2010. Until this review is complete, the program has been suspended. Some activities such as the tree audit have been allowed to continue.

In order to develop the public's understanding of and facilitate their participation in the program's planning and implementation, communications and community engagement were identified as priority investment areas.

Development of the forest audit and tree inventory approach

In April 2009 an individual condition assessment of 18,000 trees was undertaken across four Canberra suburbs, Narrabundah, Higgins, Duffy and Deakin, in which 60 individual attributes were collected. These suburbs were selected as they were geographically separate and managed by different Operational Teams within the ACT Government with a range of gazettal dates, with Deakin being one of the oldest and Duffy a middle aged suburb. Duffy was partly razed in the Canberra bushfires of 2003. The suburbs also contained a good range of demographic groups.

Results from this condition assessment project showed that although the quality of the data was excellent, the approach was unfeasible in terms of cost and time that would be required to replicate this type of audit across the city. This method also had the potential to become a "Sydney Harbour Bridge" scenario in that the job would never be complete. In addition, this level of detail wasn't suited to the development of a holistic perspective of Canberra's urban forest and thus key objectives of the UFRP might be compromised, as the data collection process could take so long and be at considerable financial cost.

The table below provides indicative calculations on the length of time to undertake a single tree assessment against the number of days in a year available for assessments.

Table 1 – Indicative calculations to assess 450,000 trees

Average minutes to assess a tree	1 min	2 mins	3 mins	4 mins	5 mins	6 mins
Average trees assessed per day	480	240	160	120	96	80
No. of days to survey 450,000 trees	937.5	1875	2812.5	3750	4687.5	5625
Years to complete for one person based on estimated survey window	7.07	14.14	21.21	28.28	35.35	42.42

Working days per year = 221 days

Estimated survey window actual survey days (days with trees in full leaf) = 132.6 days

Note: Average number of trees collected per day does not provide for breaks or travel and assumes 40hr week.

Having regard to the size, number of trees, aims and objectives of the UFRP, two assessment approaches were then developed in consultation with TreeLogic[2]. This resulted in the creation of two distinct tree assessment methods:

- **a rapid audit approach – an audit process for** the public tree resource that allows assessment of the urban forest at a strategic level ; and
- **an inventory approach** - designed for **assessment of individual** trees that allows for more specific management activities to be recorded and developed. The inventory is used in larger parks, high use areas, main arterial roads and when needed to assess the condition of a tree.

[2] TreeLogic Pty Ltd is a Melbourne based arboricultural consulting company. Part of the tender for the tree assessment in the four suburbs involved recommendations about a future approach to assessing Canberra's trees. Tree Logic recommended an audit style approach be developed. Recommendations were made to the Expert Working Group for the Program to proceed using this method.

These methods were developed as complementary activities, with the audit providing an overview of the public urban forest to enable broader management issues such as sustainability and strategic replanting programs to be developed, whereas the inventory system provides detailed information on an individual tree and its specific management requirements. The inventory approach can also be used to assess tree condition across a larger landscape unit such as a park or arterial road when more detailed information is required than that which the audit can provide.

Both approaches are based on:

- The use of spatial mapping technology such as ArcPad.
- Experienced and qualified inspectors for quality control.
- All assessments be undertaken at ground level by a qualified assessor either in a car or on foot doing visual inspections. (If further inspection is required it is noted as 'recommended works' and given a priority rating for the timing of the detailed assessment.)

The rapid audit

The rapid audit is a population-based assessment method that collects information on street or park units and ranks them in order of *risk, maintenance and renewal priority*. It relies on a scoring system that values certain characteristics over others to determine a 'Renewal Score'. The ten attributes that were scored include risk, landscape quality, planting style, age, life expectancy, species diversity, tree health, structure, site constraints and the number of planting opportunities in each assessed unit.

Each scoring field is rated from 0-5. Street tree renewal scores can range from 0 to 50, with a higher score indicating a greater priority for renewal. The following ten attributes are included in the Renewal score**.**

Audit field within the renewal score – streets (maximum of 50)

Field	Description	Comments
Borrowed landscape quality	Condition of surrounding landscape.	Contribution rating from landscape adjoining unit being assessed. A good borrowed landscape receives a higher renewal score than a poor borrowed landscape.
Street planting style	Style of street planting.	Rating assigned to different planting styles in streetscape with homogeneous avenues receiving lower renewal scores and mixed plantings or "no theme" receiving higher renewal scores.
Risk zone	Level of potential risk based on frequency of people or property.	Included in renewal score or risk score. Higher risk zones receive a higher renewal score than lower risk zones.
Estimated age of planting	Average age in years of dominant tree planting species.	Age related score with older trees receiving higher renewal scores than more recently planted trees.
Useful life expectancy	Remaining life in years for dominant planting.	Life expectancy score with longer useful life expectancy receiving lower scores than shorter useful life expectancy.

Total no. of species in the unit (count)	Species count for the unit.	Street audit field where fewer species receive lower scores and multiple species receive higher scores.
Dominant tree health	Health class rating.	Score assigned for tree health with better health receiving lower scores and poorer health receiving higher scores.
Dominant tree structure	Structure class rating (of the dominant species).	Score assigned for tree structure with better structure receiving lower score and poorer structure receiving higher scores.
Site constraints	Level of site constraints in relation to the dominant species.	Score assigned with limited constraints to tree growth and development receiving lower scores than sites with more constraints.
No. of vacant sites (count)	Planting sites in unit.	Street audit field – score assigned with fewer vacant sites in a unit receiving lower score than units that have a higher percentage of vacant sites.

Parks were also assessed using this method. The renewal scoring was modified to be a maximum of 30 or a minimum of 0. Each scoring field is rated from 0-5. The following 6 fields are included in the Renewal score:

Park unit renewal scored maximum of 30

Field	Description	Comments
Borrowed landscape quality	Condition of surrounding landscape.	Contribution rating from landscape adjoining unit being assessed. A good borrowed landscape receives a higher renewal score than a poor borrowed landscape.
Risk zone	Level of potential risk based on frequency of people or property.	Included in renewal score or risk score. Higher risk zones receive a higher renewal score than lower risk zones.
Estimated age of planting	Average age in years of dominant tree planting species.	Age related score with older trees receiving higher renewal scores than more recently planted trees.
Useful life expectancy	Remaining life in years for dominant planting.	Life expectancy score with longer useful life expectancy receiving lower scores than shorter useful life expectancy.
Dominant tree health	Health class rating.	Score assigned for tree health with better health receiving lower scores and poorer health receiving higher scores.
Dominant tree structure	Structure class rating (of the dominant species).	Score assigned for tree structure with better structure receiving lower score and poorer structure receiving higher scores.

Vacant sites and planting theme isn't included in the renewal score for parks.

An additional scoring system was also included to calculate a risk ranking score. The score is calculated by adding three fields together. Two of these fields are also included in the 'Renewal Score' calculation (risk zone and dominant tree structure). The addition of tree size provided a risk ranking score with a maximum score of 15.

Audit fields within risk score system

Field	Description	Comments
Risk zone	Level of potential risk based on frequency of damage to people or property.	Included in renewal and risk score. Higher risk zones receive a higher renewal score than lower risk zones.
Dominant tree structure	Structure class rating.	Score assigned for tree structure with better structure receiving lower scores compared with poorer structure.
Tree size	Size class.	Risk rating field not used in renewal score.

To maximise efficiency in the field a number of GIS layers were incorporated into the ArcPad including:

- Aerial images for all suburbs.
- Suburb layer.
- Property layer.
- Street address layer.
- Kerb layer.
- Road layer.
- Urban open space layer.

Other data sources were also made available

- DISMUT data (street by specie DISMUT 2009.xls)
- Pryor L.D and Banks J.CC 2001. Trees and Shrubs in Canberra, ACT Government, Little Hills Press, NSW
- Gazettal dates for suburbs and roads of Canberra

Prior to its roll out across Canberra the 'rapid population audit' was piloted in December 2009 in two Canberra suburbs, Higgins[3] and Hackett. The pilot study demonstrated that the audit approach was methodical, replicable and an efficient way to strategically analyse a large tree population. It also showed that individual units could be identified if they were more degraded than other units. This was an important issue to help provide some guidance in prioritising one region, suburb or street over another to help determine where the ACT Government needs to focus its efforts.

The pilot of the audit also provided an opportunity to make minor modifications prior to it being conducted throughout the city. Scoring modifications were needed when a landscape unit had few or no trees (although this wasn't a frequent occurrence).

Canberra individual tree inventory

Canberra's urban trees are predominantly managed in-house by four Operations Teams located throughout the city. These teams are managed by the Urban Tree Unit within the ACT Government Department of Territory and Municipal Services. The individual tree inventory assessment was initially developed to provide the Tree Operations Teams and Urban Tree Unit with a consistent approach to tree condition assessments across the city. The Department had experienced considerable criticism from the public about the inconsistencies of tree assessments in respect to tree removal or retention. Without a consistent set of criteria it was very difficult to compare decisions as to why a tree should be removed, retained for habitat or pruned. A consistent assessment method was also essential to useful data capture on the Territories' integrated database (IAMS). The assessment approach once again needed to be designed for the scale (number) of trees within the urban forest and used as a starting point in the future management of the tree.

The individual tree condition assessment uses GPS technology and an electronic form, with drop-down menus to maximise efficiency, and reduce the opportunity for error. The computer version of the form has a scoring system which is linked to the Territory's risk rating matrix. The form is loaded onto robust laptops for field use and the information, once recorded, is downloaded into the city's **Integrated Asset Management System (IAMS).**[4] Digital images accompany the assessment.

[3] Higgins was assessed using both the rapid audit approach and the individual inventory system to check the quality of the data and tree counts etc.

[4] The individual assessment method was initially trialled using a paper based assessment form. It is currently being rolled out across the Operational Teams

The individual assessment can be used as a strategic planning tool when applied across larger landscape units such as parks, when the rapid assessment approach is less informative and also as a tool to inform specific management of a tree flowing from resident requests and when a tree requires removal.

It is not anticipated that this individual assessment approach will be applied across Canberra's urban forest in the near future. Work is however being undertaken to capture information about new trees at the time of planting and after work has been undertaken as a starting point to a more proactive cyclic management regime.

The Tree Condition Inventory form is designed to meet criteria of the IAMS which uses a parent – child relationship for attribution of assets. A list of attributes is provided in the tables below.

Attributes of the parent asset

Field	Type	Description
IAMS asset ID	Auto	Identification number auto-generated when entered into IAMS
Contractor tree ID	Auto	Identification number supplied by contractor
Suburb	List	List of all suburbs
Location type	List	Street tree or Open Space tree
Location number	Text	House number if applicable
Location street name	List	Asset name of street
Location UOS name	List	Name of town park or Urban Open Space type (used in relation to road name)
X coordinates	Auto	GPS, GIS/aerial photo or referenced survey
Y coordinates	Auto	GPS, GIS/aerial photo or referenced survey
Heritage status	Auto	No, Provisional Registration, Full Registration (Appears on form, but not collected in field)
Registered tree	Auto	No, Provisional Registration, Full Registration (link to Register page / tree management plan – PDF) (Appears on form, but not collected in field)
Tree of interest	List	No / Yes – Tree to be considered for heritage or registration protection
Designated land	Auto	No / Yes (Appears on form, but not collected in field)
Genus species	List	List of commonly found species in Canberra (IAMS format)
Provenance	Text	Record nursery and seed source if known
Planting date	Year	If known, or estimated to mid decade, e.g. 1965
WAE / Project Number	Text	Reference number from 'Works as Executed' plans, Capital Works projects or program name, e.g. Million Trees
Collector name	Text	Staff name or contracting company name
Collection date	Auto	Date the tree is inspected and data recorded

Tree condition assessment fields - child

Field	Description					
DBH	Number	Diameter of largest stem measured at 1.3 m above ground. Estimate to nearest 5 cm. If multiple stems, record additional stems (up to 5) in comments field. If branch union at 1.3 m adjust measurement higher or lower.				
Tree Height (Scored)	Very Large (5) >20 m	Large (4) 12-20 m	Medium (3) 6-12 m	Small (2) 3-6 m	Very Small (1) <3 m	Vacant (0)
Health (Scored)	Dead (5) Trunk, primary branches and twigs dead; no leaves or dead leaves	Very Poor (4) Irreversible decline; 30-50% dieback; severe foliage deficiencies; 30-50% foliage density; 30-50% leaf health; severe pests / diseases	Poor (3) Minimal vigour; substantial decline; 20-30% dieback; considerable foliage deficiencies; 50-70% foliage density; 50-70% leaf health; pest / diseases exceed thresholds	Fair-Poor (2) Below average vigour; more than average decline; 10-20% dieback; foliage deficiencies; 70-90% foliage density; 70-90% leaf health; pests / disease at thresholds	Fair (1) Average vigour; average decline; <10% dieback; >90% foliage density; >90% leaf health; pests / diseases within thresholds. The typical condition of the species.	Good (0) Above average vigour; no decline; 0% dieback; better than average foliage density; better than average leaf health; no pest / diseases. An exceptional specimen.
Structure (Scored)	Failed (5) Failure of root plate, trunk or primary branch; active split between branch unions; severe damage to primary tree structure	Very Poor (4) Excessive damage or decay to root plate, trunk, primary branches or branch unions; fungal fruiting bodies; excessive decay or hollows compromising structural integrity; unstable in ground; excessive branch end-weight; severe included-bark unions; exceeding thresholds – failure probable	Poor (3) Major damage or decay to root plate, trunk or primary branches; no observable basal flare; acute branch unions starting to include bark; major branch end-weight / over-extension; at or exceeding thresholds	Fair-Poor (2) Moderate damage or decay in root plate, trunk or primary branches; minimal basal flare; acute branch unions; past branch failure; moderate branch end-weight / over extension; approaching thresholds	Fair (1) Minor damage or decay to root plate, trunk or primary branches; typically formed branch unions; minor end-weight / over-extension; within thresholds. Standard tree – no observable major defects to suggest that there is an increased likelihood of tree failure.	Good (0) No damage or decay; visible basal flare; stable in ground; well tapered branches with sound open unions. An exceptional specimen.

Useful Life Expectancy (ULE) (Scored)	0-10 Years (5)	10-20 Years (4.5)	20-30 Years (4)	30-40 Years (3.5)	40-50 Years (3)	50-60 Years (2.5)	60-70 Years (2)	70-80 Years (1.5)	80-90 Years (1)	90-100 Years (0.5)	100+ Years (0)

Risk Zone (Scored)	Prominent (5) Highway / arterial road; 40km/hr school zones; adjacent to retail premises; shopping centres; 10 m buffer from edge of BBQs, seats, shelters, toilet blocks, car parks, picnic tables, cycleways and paths in UOS	Major (4) Major collector roads; Category A Maintenance Areas – High Use; Town park	Moderate (3) Minor collector roads; Category A Maintenance Areas – Medium Use; District park	Minor (2) Access roads; Category A Maintenance Areas – Low Use; Pedestrian Parkland; Laneway; neighbourhood park	Minimal (1) Category B Maintenance Areas	N/A (0)
Risk Score	Calculated	The sum of the individual scores for: Tree Height, Health, Structure, SULE and Risk Zone – maximum 25				
TAMS – Risk Level	Auto	TAMS Management Actions and Responses to Risk Assessment Levels – automatically determined by risk score – see attached Table – Extreme, Very High, High, Medium, Low, Very Low				
Utility Lines (In close proximity to tree)	High Voltage – HV	Low Voltage – LV	Domestic / Service	Telco	Aerial Bundle Cable – ABC	None
Footpath Conflict	Tick box	Observable damage to footpath that may reasonably be attributed to the tree, including vertical deflection, lips or cracks. Add comments if required.				
Verge Crossing Conflict	Tick Box	Observable damage to verge crossing that may reasonably be attributed to the tree, including vertical deflection, lips or cracks. Add comments if required.				
Road Conflict	Tick Box	Observable damage to road surface that may reasonably be attributed to the tree, including vertical deflection, root patterns, lips or cracks. Add comments if required.				
Kerb & Channel Conflict	Tick Box	Observable damage to kerb & channel that may reasonably be attributed to the tree, including deflection, lips, cracks or roots growing over. Add comments if required.				
Utility Line Conflict	Tick Box	Direct or potential crown interference with utility lines. Add comments if required.				
Street Furniture Conflict	Tick Box	Crown or root conflict with street signs, light poles, utility poles, bus shelters, service pits, seats, etc. Add comments if required.				
Line-of-Sight Conflict	Tick Box	Part of the crown is obscuring an important sight line. Add comments if required.				
Utility Box/Stn Conflict	Tick Box	Access to Utility/electrical box on nature strip or electrical/sewage pumps stn obstructed by vegetation pipe. Add comments if required.				

Underground Services Conflict	Tick Box	Observable damage to underground services that may reasonably be attributed to the tree, such as roots removed from drain, or deflection of pipe. Add comments if required.				
Private Infrastructure Conflict	Tick Box	Observable damage to private infrastructure that may reasonably be attributed to the tree, such as lifting fences / walls, deflection of driveways, cracking in house wall. Add comments if required.				
Recommended Work Type	Hazard Tree Assessment More detailed assessment required – aerial inspection / probe; unclear evidence of decay, termites, bird damage, etc.	Removal Tree condition cannot be alleviated by contemporary arboricultural practices	Utility Line Clearance Pruning around or over utility lines to create suitable clearance	General Maintenance – Mature Mature / large trees – dead wood removal (>50mm ∅/ 2m length); crown thinning; crown lifting; reduction pruning; selective or structural pruning	General Maintenance – Juvenile Young and semi-mature trees – dead wood removal; crown lifting; formative pruning	None No obvious works required
Work Priority	Urgent 48hrs	High 2 Weeks	Medium 3 Months	Low 6 Months	Very Low 12 Months	None N/A
Comments	Text	General comments if required or if removal recommended (use codes).				
Marked for Removal	List	No; Pink Cross; Pink Dot; Yellow Cross; Yellow Dot; Blue Cross; Blue Dot; Green Cross; Green Dot. A consistent colour will be used across Canberra to indicate removals; the colour will change each year and specified by Program Manager Urban Trees; dots indicate removals by contractors; crosses indicate removal by PCL staff.				
Assessment Date	Auto	Date the tree is assessed and data recorded.				

Note: The assessment included descriptions for health assessment definitions such as useful life expectancy and risk zone ratings from prominent (5) to minor (–2).

Results

From March to May 2010, the rapid audit was used to assess tree condition across 460,000 trees - approximately 80%[5] of Canberra's urban forest. Preliminary results are provided in the table below.

<table>
<tr><td>Total trees in audit
Total street trees
Total planting opportunities in streets</td><td>460,000
263,000
20,300 (streets)</td></tr>
<tr><td>Count of top 20 combined dominant, secondary & tertiary species name and count
(Accounts for 61% of all trees)</td><td>
<table>
<tr><td>Species</td><td>Count</td><td>%</td></tr>
<tr><td>Eucalyptus mannifera</td><td>79538</td><td>29.07%</td></tr>
<tr><td>Casuarina cunninghamia</td><td>36615</td><td>13.38%</td></tr>
<tr><td>Pinus radiata</td><td>17406</td><td>6.36%</td></tr>
<tr><td>Eucalyptus polyanthemos</td><td>17056</td><td>6.23%</td></tr>
<tr><td>Eucalyptus sp.</td><td>16032</td><td>5.86%</td></tr>
<tr><td>Eucalyptus melliodora</td><td>15659</td><td>5.72%</td></tr>
<tr><td>Eucalyptus spp.</td><td>11668</td><td>4.26%</td></tr>
<tr><td>Eucalyptus cinerea</td><td>9685</td><td>3.54%</td></tr>
<tr><td>Quercus palustris</td><td>8468</td><td>3.09%</td></tr>
<tr><td>Eucalyptus blakelyi</td><td>8377</td><td>3.06%</td></tr>
<tr><td>Populus alba</td><td>7549</td><td>2.76%</td></tr>
<tr><td>Eucalyptus sideroxylon</td><td>7024</td><td>2.57%</td></tr>
<tr><td>Fraxinus oxycarpa</td><td>5334</td><td>1.95%</td></tr>
<tr><td>Fraxinus raywood</td><td>5254</td><td>1.92%</td></tr>
<tr><td>Eucalyptus bicostata</td><td>5233</td><td>1.91%</td></tr>
<tr><td>Pyrus calleryana</td><td>5143</td><td>1.88%</td></tr>
<tr><td>Eucalyptus nicholii</td><td>5054</td><td>1.85%</td></tr>
<tr><td>Ulmus parvifolia</td><td>4938</td><td>1.80%</td></tr>
<tr><td>Liquidambar styraciflua</td><td>3898</td><td>1.42%</td></tr>
<tr><td>Platanus x acerifolia</td><td>3698</td><td>1.35%</td></tr>
<tr><td></td><td>273, 629</td><td></td></tr>
</table>
</td></tr>
<tr><td>Dominant species as a percentage of total trees in each unit</td><td>Average = 61%</td></tr>
<tr><td>Secondary species name</td><td>MIXED sp. dominant by small percentage over
Eucalyptus spp</td></tr>
<tr><td>Species 1 as a percentage of total trees</td><td>Average = 18.7%</td></tr>
<tr><td>Count of very poor or dead trees</td><td>Park 7890</td></tr>
</table>

[5] It was intended to complete all suburbs but seasonal conditions prevented completion of the audit in the timeframe. It is hoped to complete the audit in 2011.

	Street 8930 **16, 820** 3.74% of assessed trees
Count of young trees	Total 21,839 or 4.86% of total trees

General recommendation on how to manage unit			
	Infill	860	10.9%
	Maintain	4919	62.5%
	No planting opportunity	749	9.5%
	Other - comment	41	0.5%
	Partial renewal	632	8.0%
	Planting opportunity	464	5.9%
	Renewal	211	2.7%

It is interesting to observe that in terms of sustainability, the current (and predicted future) age or size class distribution for Canberra's urban trees does not meet McPherson's[6](1998) features of a sustainable urban forest. His research suggests adequate species and age diversity. Common prescriptions include having no single species accounting for more than 5-10% of the entire population and a good age/size diversity with 40% of trees at less than 20 cm dbh, 30% at 20-40 cm dbh and 20% at 40-60 dbh and 10% older. The Eucalyptus genus dominated the planting in Canberra making up 56% of all trees in parks and streets. Replanting should therefore not necessarily replace like with like in order to reduce the overall number of Eucalypt.

In late December 2009 to February 2010, the inventory approach was used in two of Canberra's oldest parks, Corroboree and Glebe Parks and along Northbourne Avenue, the major arterial into Canberra from Sydney. Data from these inventories is being used to develop specific management plans for these locations in conjunction with community groups and residents adjacent to the sites.

Comments and recommendations

An audit is an audit and should be used as a management tool for planning at a strategic level. Its strength is that it can efficiently provide information on tree condition and is considerably less costly and quicker than other assessment methods. It relies on a scoring system that is linked to the dominant tree type and therefore may not be as helpful in park situations where it may be difficult to determine the dominant tree species. An individual inventory assessment approach provides the detail that may be needed to manage these sites.

The audit cannot gauge peoples' opinions about trees and thus it does not provide a context to peoples' desire for or angst about trees. For example, a trial exercise was recently undertaken, where information from the audit on a street with a high number of vacant sites was aligned with a resident enquiry for tree replanting. Approximately 30 residents were notified via letter box drop advising them that trees would be (re)planted in their street. Within two days of receiving the notice, five residents responded requesting that a tree not be (re)planted. In management terms, the Government then needs to consider value in (re)planting trees when residents have requested otherwise.

The audit provides useful observations about the actions of residents when trees are either planted that they don't like or not replanted after removal or failure (death) when newly planted. The audit results show that a high number of streets have highly variable and inconsistent street trees.

[6] **Brack, C.L.** (2005) Environmental, amenity and Habitat Values of an Urban Forest: How to determine and manage for them in Canberra. *Proceedings of the 9th Annual ISAAC National Conference*. Launceston, Tasmania. September 30th - October 5th, 2005. P 19.

Reviewing records for these sites shows that (re)planting may not have been undertaken since the original plantings. It can therefore be assumed the resident has planted their own tree, many of which are now mature. Issues around the management of privately planted trees can be problematic as work can be difficult to schedule as these trees may have different needs, the resident often has considerable ownership and may resent pruning work being undertaken as well as the siting and ongoing safety issues. However it may not be a prudent decision to remove these trees just because they were not official streets trees.

The audit initially highlighted considerable vacant sites where trees could be planted in laneways. These areas were of less importance in overall terms for replanting than streets and arterial roads. Given the scale of the issue in Canberra, decisions will need to be made on the tree management priorities in terms of location and replacement species.

Some conclusions

Information from the audit and inventory are starting points for future management plans of the urban tree estate. Community interests and government responsibilities and priorities are equally important components in the success of future management plans.

An understanding of the detail that can be provided by an audit to that of an inventory is essential. The audit relies on averages to provide efficiencies and allows for data collection at a broad scale which can be used in a strategic planning sense. Information from the inventory however is also essential to more specific management of urban trees.

The scoring fields used in the audit have been designed to rank streets and parks according to ten attributes. The results show there is sufficient variation in the quality of the units to establish a rank or order based on these scoring fields. This scoring system allows the condition of trees at a regional, suburb or street level to be compared although in some cases there may not be great variations between results.

The audit approach provides a snapshot of a landscape unit's condition in time. The accuracy of the information will deteriorate unless updated. Consideration needs to be given to the timeframe and process for updating the information.

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- GHD Consulting - Melinda Mylek and Tim Brown
- Homewood Consulting Pty Ltd - Ben Kenyon, Cameron Ryder, Aaron Provis, Blake Clancy
- TreeLogic Pty Ltd - Dean Simonsen, Michael Tracy, Bruce Callander, Greg Pollard

Urban forest renewal program, Territory and Municipal Services (TAMS) involved in project:

Russell Watkinson, Jane Carder, Michael Brice, Prue Buckley, Julie Garbode, Ryan Lawrey, Samantha Ning, Matthew Parker, Sarah Twohill

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Invitation to 2011 Institutional Membership (Associations)

Institutional Membership of TREENET is open to all not-for-profit organisations with an interest in urban trees.

Industry Associations are eligible for Institutional Membership (Associations) status, valid until 31st **December 2011** for the annual investment of **$600** (exc GST).

TREENET:

- **TREENET** (Tree and Roadway Experimental and Educational Network) is the National Research and Education organisation for urban trees. It is a not for profit organisation based at the University of Adelaide's Waite Arboretum.
- **TREENET** is advised by a National Board of over 50 voting members who have been selected for their expertise in relevant fields.
- **TREENET** maintains a freely accessible website www.treenet.org with information on all aspects of urban trees and related technologies and products.
- **TREENET** is the founding organisation responsible for the coordination, management, and promotion of The Avenues of Honour 1915-2015 Project. **www.avenuesofhonour.org**

The Benefits:

- Complimentary attendance, for one Elected Member, or other Honorary Position within your organisation at the 12th National Street Tree Symposium at the National Wine Centre and the Waite Arboretum 1st-2nd September 2011.
- A 20% discount on the registration cost for selected TREENET events such as Symposia will apply to all financial members of your organisation attending the annual symposium. This substantial benefit will be a great reward for belonging to your organisation. On ordering through our shopping cart each of your members can receive the discount by quoting the discount coupon code exclusive to your organisation.
- A free copy of the Symposium proceedings will be mailed to your organisation after September 2011.
- Your organisation has the right to promote your membership of TREENET in all publications and media in the current financial year.
- You will receive a certificate suitable for framing for public display acknowledging your membership.
- Your organisation will be listed as an Institutional Member at www.treenet.org with a direct link provided to your website.
- By supporting TREENET you are contributing to the efficient and effective management of our urban forests and helping to ensure the continuation of research programs of direct benefit to your organisation and to the wider community.

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Invitation to Institutional Membership 2011
(Government, Research, and Educational Organisations)

Institutional Membership is open to Local, State and Federal government bodies that have an interest in promoting research and education relating to urban trees, particularly those in the public domain. Individual membership is not offered. The cost is $900 (exc. GST) per calendar year, renewable each January.

TREENET:

- **TREENET** is the National Research and Education organisation for urban arboriculture based at the University of Adelaide's Waite Arboretum.
- **TREENET** maintains a freely accessible website **www.treenet.org** with up to date information on all aspects of urban trees, related technologies, products and services.
- **TREENET** is the founding organisation responsible for the coordination, management, and promotion of The Avenues of Honour 1915-2015 Project. **www.avenuesofhonour.org**

The Benefits:

- Complimentary attendance, for one Elected Member, or other Honorary (unpaid) individual from your organisation at the 12th National Street Tree Symposium at the National Wine Centre and the Waite Arboretum 1st-2nd September 2011.
- A 20% discount on the registration cost will apply to all paid staff of your organisation attending the Symposium or the Post Symposium tour. Also we will be adding further items to our shopping cart such as the TREENET kerb inlet which will be substantially discounted for Institutional Members. These discounts will be accessed online via a coupon code unique to your organisation.
- Your organisation will be eligible to participate in TREENET trials. TREENET is producing small numbers of trees for trialling in your neighbourhood that may be better adapted to the changing climatic conditions affected by global warming. These uncommon species are sourced from the Waite Arboretum and elsewhere and will be made available at cost exclusively to Institutional Members. IM's will also have priority access to emerging stormwater technology such as the TREENET kerb inlet.
- Your organisation has the right to promote your Institutional Membership of TREENET in all publications and media in the current financial year.
- Acknowledgement of your organisation's Institutional Membership status will be provided online with a direct link to your website. You will also receive a Certificate of Appreciation to promote your commitment to the urban forest and in particular the aims of TREENET.
- By supporting TREENET you are contributing to the efficient and effective management of our urban forests and helping to ensure the continuation of research programs of direct benefit to your organisation and to the wider community.

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Treenet Sponsorship Packages (for the 2011 calendar year)

Bronze $2000 (+gst) 20 packages available 2011

- Right to promote Treenet sponsorship.
- Framed Certificate presented at the 12th National Street Tree Symposium 1st -2nd September 2011.
- Website exposure (1 time unit per sponsor).
- Direct link from **www.treenet.org** to your business website.
- Acknowledged in Symposium proceedings and on conference banners (text only no logo).
- Promotional material can be included in Symposium satchels.
- Free poster display space available at Symposium (up to one side of standard display board).
- 1 Symposium seat and 20% discount on additional attendances.

Silver $4000 (+gst) 6 packages available 2011

- Right to promote Treenet sponsorship.
- Framed Certificate presented at the 12th National Street Tree Symposium 1st -2nd September 2011.
- Website exposure (2 time units per sponsor).
- Direct link from **www.treenet.org** to your business website.
- 1 separate page on website made available for your own promotional messages. You have access to update info when you wish.
- Acknowledged in Symposium proceedings and on conference banners (logo).
- Promotional material can be included in Symposium satchels.
- 1 free trade display space at Symposium.
- 2 Symposium seats and 20% discount on additional attendances.

Gold $8,000 (+gst) 2 packages available 2011

- Right to promote Treenet sponsorship.
- Framed Certificate presented at the 12th National Street Tree Symposium 1st -2nd September 2011.
- Website exposure (4 time units per sponsor).
- Direct link from **www.treenet.org** to your business website.
- 2 separate pages on website made available for your own promotional messages. You have access to update info when you wish.
- Acknowledged in Symposium proceedings and on conference banners (logo).
- Promotional material can be included in Symposium satchels.
- 2 free trade display spaces at Symposium.
- 4 Symposium seats and 20% discount on additional attendances.

Platinum $16,000 (+gst)   1 package available 2011

- Right to promote Treenet sponsorship.
- Framed Certificate presented at the 12th National Street Tree Symposium 1st -2nd September 2011.
- Website exposure (permanent display at top of each page).
- Direct link from **www.treenet.org** to your business website.
- 4 separate pages on website made available for your own promotional messages. You have access to update info when you wish.
- Acknowledged in Symposium proceedings and on conference banners (logo).
- Promotional material can be included in Symposium satchels.
- 4 free trade display spaces at Symposium.
- 8 Symposium seats and 20% discount on additional attendances.
- Invitation to address delegates at 2011 Symposium.