THE UNIVERSITY of ADELAIDE

treenet

Proceedings of the

14th National Street Tree Symposium 2013

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TREENET Proceedings of the 14th National Street Tree Symposium 2013
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INSTITUTIONAL MEMBERS OF TREENET 2013

ASSOCIATIONS

Australian Institute of Landscape Architects SA (AILA SA)
Institute of Australian Consulting Arboriculturists (IACA)
Arboriculture Australia Ltd
Local Government Tree Resources Association (NSW)
Nursery & Garden Industry SA Inc (NGISA)
Queensland Association of Arboriculture (QAA)
Council Arboriculture Victoria

GOVERNMENT

Adelaide City Council
Albury City Council
Brisbane City Council
Campbelltown City Council
Banyule City Council
City of Belmont
City of Burnside
City of Charles Sturt
City of Holdfast Bay
City of Marion
City of Melbourne
City of Mitcham
City of Norwood, Payneham and St Peters
City of Onkaparinga
City of Playford
City of Port Adelaide Enfield
City of Salisbury
City of Subiaco
City of Sydney
City of Unley
City of West Torrens
Department Planning Transport & Infrastructure
District Council of the Copper Coast
District Council of Mount Barker
Gold Coast City Council
Hume City Council
Hurstville City Council
Marrickville Council
Maribyrnong City Council
Moorabool Shire Council
Moreland City Council
Naracoorte Lucindale Council
National Capital Authority
Newcastle City Council
ACT TAMS and Parks & City Services
Rural City of Murray Bridge
Surf Coast Shire Council
Toowoomba Regional Council
Wagga Wagga City Council
Whyalla City Council

CORPORATE

Active Tree Services
Arbor Centre
Arborman Tree Solutions
Arbortrack Australasia Pty Ltd
Austral Tree Services
Fleming's Nurseries
Homewood Consulting
HR Products
Humphris Nurseries
Metropolitan Tree Growers Pty Ltd
Mt William Advanced Tree Nursery
Quantified Tree Risk Assessment Limited (QTRA)
Sevron Environmental Contractors
TerraCottem Australasia Pty Ltd
Tree Dimensions
Trentcom APS Pty Ltd
Vermeer Sales and Service Pty Ltd

Click here to visit the TREENET website to find out more about our Institutional Members.

TREENET MANAGEMENT COMMITTEE AND ADVISORY BOARD 2013

TREENET MANAGEMENT COMMITTEE

Chairperson: Dr Greg Moore
Director: Glenn Williams *(ex officio)*
Director: David Lawry OAM *(ex officio)*
Treasurer: Brian Measday *(ex officio)*
Members: Dr Jennifer Gardner
Judy Fakes
Tim Johnson
Hon Dr Bob Such MP
John Zwar

TREENET ADVISORY BOARD

TREENET			
Glenn	Williams	Director TREENET	SA
David	Lawry OAM	Director TREENET and 1915- 2015 Avenues of Honour Project	SA
Brian	Measday	Chartered Accountant, Honorary Treasurer TREENET	SA
Robin	Eley	Chief Financial Officer 1915- 2015 Avenues of Honour Project	SA
Educational and Research Institutions			
Prof Chris	Daniels	Professor of Urban Ecology University SA Management Committee TREENET	SA
Judy	Fakes	Head Teacher Parks, Gardens & Arboriculture Ryde College of TAFE. Management Committee TREENET	NSW
Dr Jennifer	Gardner	Director, Waite Arboretum Management Committee TREENET	SA
Dr Greg	Moore	Research Assoc. Burnley School of Resource Management and Geography Chair TREENET	VIC
Dr Dean	Nicolle	Flinders University, Director, Currency Creek Arboretum	SA
John	Zwar	TAFE SA Urrbrae Campus	SA
Nursery Industry			
John	Fitzgibbon	Metropolitan Trees	VIC
Geoffrey	Fuller	CEO Nursery & Garden Industry of South Australia	SA
Hamish	Mitchell	Speciality Trees	VIC
Community			
Hon Dr Bob	Such	Independent Member for Fisher	SA
Hon Michelle	Lensink	Liberal Member Legislative Assembly	SA
Arboricultural & Allied Professions			
Jan	Allen	Terra Ark	QLD
Peter	Bishop	Bunya Solutions	QLD
Rob	Bodenstaff	Arbor Centre	WA
David	Galwey	Tree Dimensions	VIC
Phillip	Hewett	Neighbour Woods	NSW
Ben	Kenyon	Homewood Consulting	VIC
Phillip	Kenyon	Kenyon's Quality Tree Care	VIC

Kym	Knight	Tree Environs	SA
Mark	Willcocks	Active Tree Services	NSW
Quentin	Nicholls	Arbortrack	QLD

Landscape Architects and Urban Planners

Michael	Heath	Chair National Trust SA Significant Tree Committee	SA

Local Governments

Tim	Johnson	City of Mitcham	SA
Christopher	Lawry	District Council of Mt Barker	SA
Lyndal	Plant	Brisbane City Council	QLD
Jason	Summers	Hume City Council	VIC
Karen	Sweeney	City of Sydney	NSW
Vic	Bijl	City of Belmont	WA

State Governments

Henry	Polec	Department of Transport Energy and Infrastructure	SA

TREENET Incorporated

CONSTITUTION

1. NAME

The name of the Association is "TREENET Incorporated"

2. DEFINITIONS

2.1 "The Act" means the Associations Incorporations Act 1985.

2.2 "Association" means the above named Association.

2.3 "Management Committee" means the committee referred to in Rule 11.

2.4 "Advisory Board" means the Board referred to in Rule 12.

3. VISION AND AIMS

3.1 Vision

The vision of the Association is to enhance the role of trees in the urban forest and to engage the community in this endeavour.

3.2 Aims

The aims of the Association are:

3.2.1 To develop and maintain an interactive web application to facilitate the exchange of information relating to urban forests.

3.2.2 To promote research and education relating to urban forests including holding symposia.

3.2.3 To broaden the body of knowledge that exists about street trees and foster research, distribute applicable information, facilitate cooperation and enlist community support concerning the protection, preservation and enhancement of the urban forest.

3.2.4 To establish and maintain a public fund to be called *TREENET Fund* for the specific purpose of supporting the environmental purposes of TREENET Inc. The Fund is established to receive all gifts of money or property for this purpose and any money received because of such gifts must be credited to its bank account. The Fund must not receive any other money or property into its account and it must comply with subdivision 30-E of the Income Tax Assessment Act 1997.

4. POWERS

The Association shall have all the powers conferred by Section 25 of the Act.

5. MEMBERSHIP

5.1 Membership

When an organisation or person has agreed to become a member of the Association and has paid the Association's membership fee where it applies, then that organisation or person will be admitted to membership pursuant to the Constitution, and their name shall be entered in the Association's Register of Members.

5.2 Classes of Member

There shall be five classes of member:

5.2.1 **Management Committee Member**

This class shall consist of all members of the Management Committee as described in Rule 11.1. Management Committee Members will have the right to receive notice of and attend all meetings.

5.2.2 **Advisory Board Member**
This class shall consist of natural persons who have been invited by the Management Committee to be on the Advisory Board and agreed. Advisory Board Members will have the right to receive notice of, and attend, the Annual General Meeting and other General Meetings as called. The term of appointment will be for the calendar year.

5.2.3 **Associate Member**
This class shall consist of natural persons who register an interest in joining the Association and who subscribe to the aims of the Association.

5.2.4 **Institutional Member**
This class shall consist of research and educational institutions, government bodies, businesses and associations who are financial members. Institutional Members will have the right to receive notice of, and attend, the Annual General Meeting and other General Meetings as called.

5.2.5 **Honorary Life Member**
This class shall consist of natural persons who have been granted Honorary membership at the discretion of the Management Committee. Honorary Life Members will have the right to receive notice of and attend the Annual General Meeting and other General Meetings as called.

5.3 Votes
Members may exercise the following voting entitlements:

5.3.1 Management Committee Member – 1 vote

5.3.2 Advisory Board Member – 1 vote

5.3.3 Associate Member – members of this class shall have no votes

5.3.4 Institutional Member – financial members – 1 vote by representation or proxy

5.3.5 Honorary Life Member – 1 vote

5.4 Register of Members
A Register of Members shall be kept which contains the name, postal or electronic address, class of membership and subscription details of each Member and the date of joining the Association.

5.5 No Transfer of Rights
The rights and privileges of a Member shall not be transferable and shall cease upon such an organisation or person ceasing to be a Member.

6. MEMBERSHIP FEES
The Management Committee shall from time to time set the terms and conditions of membership fees, if any, for the different classes of membership.

7. CESSATION OF MEMBERSHIP
Membership may cease by resignation, expulsion or non payment of fees.

7.1 Resignation
Members shall cease to be a member by notifying the Association by whatever means the Management Committee might direct from time to time.

7.2 Expulsion
If any Member wilfully refuses or neglects to comply with the provisions of the Constitution, or is guilty of any conduct which in the opinion of the Management Committee is unbecoming to a Member or prejudicial to the interests of the Association, the Committee shall have the power to

expel the member from the Association PROVIDED THAT at least one month before the Committee Meeting at which a resolution for the Member's expulsion is to be considered, the Member shall have been given notice of such meeting and what is alleged against them and of the intended resolution for their expulsion, and they shall at such meeting and before the passing of such resolution have had an opportunity to give oral or written explanation for their defence.

7.3 Non-payment of Fees
If a Member has not paid fees as agreed in the terms and conditions and has been notified in writing by the Association of this failure, then the Member shall cease to be a Member of the Association unless the prescribed fee is paid by the date as notified.

8. PROPERTY AND FINANCE

8.1 The funds and other property of the Association shall be managed and controlled by the Management Committee and shall be used only for the vision and aims of the Association.

8.2 All cheques, negotiable instruments and orders drawn by the Association shall be signed by two persons designated by the Management Committee.

8.3 Subject to Rule 8.1, the surplus funds of the Association may be invested in such manner as the Management Committee sees fit, except direct equities.

8.4 The accounts of the Association shall be audited annually.

8.5 The financial year of the Association shall be from 1 July to 30 June.

8.6 The Association shall prepare financial accounts at the end of each financial year.

9. NOT-FOR -PROFIT

The assets and income of the Association shall be applied solely in furtherance of its above-mentioned vision and aims and no portion shall be distributed directly or indirectly to the members of the Association except as bona fide compensation for services rendered or for reimbursement for expenses incurred.

10. MEETINGS OF THE ASSOCIATION

10.1 The Annual General Meeting shall be held at such time as the Management Committee shall determine.

10.2 Any Motion that any voting Member proposes to move at the Annual General Meeting including a proposal to alter the Constitution shall be given in writing to the Management Committee at least four weeks before the meeting.

10.3 At least 21 days before the Annual General Meeting or any other General Meeting, notice shall be given by written or electronic form sent to all members of the Association entitled to vote, but any accidental omission to give notice to any voting member shall not invalidate the meeting.

10.4 At the Annual General Meeting, ordinary business shall be the presentation of the audited financial accounts, election of the Management Committee and the appointment of an auditor.

10.5 Each voting member present shall be entitled to one vote. In case of an equality of votes, the Chair shall have a second or casting vote.

10.6 A Special General Meeting may be requested by ten voting members presenting an agenda to the Management Committee, the agenda being signed by all ten members. The Management Committee must within 14 days give notice of a Special General Meeting to be at least 21 days from the notice date. The Special General Meeting will be limited to the agenda items plus other items of which the Committee gives notice. Once the agenda items have been resolved by consensus, resolution or vote they cannot be used again to call a Special General Meeting for 52 weeks from the meeting date.

10.7 An Advisory Board Member shall be entitled to appoint in writing a natural person, who is also an Advisory Board Member of the Association, to be his or her proxy, and to vote on his or her behalf at any general meeting of the Association.

11. MANAGEMENT COMMITTEE

11.1 Membership of the Management Committee

The Management Committee will comprise six elected members drawn from education and research, business and government sectors of the community and three *ex officio* members as follows:

11.1.1 An academic from a tertiary educational institution

11.1.2 A member of Local Government

11.1.3 Four other members

11.1.4 The Director of Waite Arboretum will be a member *ex officio* and may also represent The University of Adelaide with consent from the University

11.1.5 The Directors of Treenet and the Treasurer of Treenet will be members *ex officio*.

11.2 Elections

11.2.1 The elected members of the Management Committee shall be elected annually by voting members of the Association at the Annual General Meeting.

11.2.2 Where the number of candidates for membership of the Management Committee exceeds the maximum number, elections shall be held by secret ballot of members at the Annual General Meeting entitled to vote. In the case of an equality of votes, the Chair shall have a second or casting vote.

11.2.3 The nomination of a candidate for membership of the Management Committee must be in writing, signed by a proposer (who must be an Advisory Board member) and by the nominee. The nomination must be delivered to the Director of the Association before such time as the Management Committee shall determine.

11.2.4 Subject to Rule 11.1, the Management Committee shall have the power to co-opt further Committee members and to fill casual vacancies.

11.3 Office Bearers

The Office Bearers of the Association shall be:

Chair
Directors & Public Officer *ex officio*
Treasurer *ex officio*

11.4 Procedures Generally

The Management Committee may meet in person or confer by video or telephone conferencing, email or by other electronic means for the dispatch of business and subject to the Constitution, otherwise regulate its meetings as it thinks fit.

11.5 Calling of Committee Meetings

11.5.1 The Management Committee shall meet or confer at least four times per year as described in 11.4. Notice of the meeting or conference shall be given in writing to each Committee Member.

11.5.2 The position of any Committee member absent for three consecutive meetings or conferences without leave of absence shall automatically become vacant. Acceptance of an apology shall be deemed grant of such leave.

11.6 Chair
The Chair shall take the chair at meetings. In his or her absence, the Committee shall appoint a member of the Committee to chair the meeting.

11.7 Decisions of Questions
Questions arising before a meeting of the Committee shall be decided by a majority vote. In case of an equality of votes, the chair shall have a second or casting vote.

11.8 Reporting
The Management Committee shall be responsible to the Association and shall present an annual report, including the audited financial accounts, to each Annual General Meeting.

11.9 Auditor
The Management Committee shall appoint an auditor of the Association, who will hold office until the next Annual General Meeting of the Association.

12. ADVISORY BOARD

12.1 There shall be an Advisory Board of the Association.

12.2 The Advisory Board will comprise persons who are competent and willing to provide advice to the Association in their individual areas of expertise, and to liaise with other bodies and institutions for the purpose of facilitating the flow of information between the Association and those other bodies and institutions, and facilitating the implementation of projects which the Association undertakes in furtherance of its aims.

12.3 Members of the Advisory Board shall have no power or authority to represent the Association in any dealings between the Association and third parties.

12.4 The Advisory Board shall meet at such times and places as the Management Committee shall determine.

12.5 The Chair of the Management Committee will take the chair at meetings of the Advisory Board.

13. QUORUMS

13.1 The quorum at general meetings of the Association shall be six members entitled to vote.

13.2 The quorum at Management Committee meetings shall be three members.

14. AUTHORITY TO ENTER INTO CONTRACTS OR AGREEMENTS

The Association shall not be committed to any binding contract or Agreement except pursuant to a resolution of the Management Committee and the instrument shall be signed by at least two members of the Committee.

15. DISSOLUTION

15.1 The Association shall be dissolved if a resolution to this effect is carried by a three-quarters majority voting in person or by proxy at a general meeting, 21 days notice of the proposed resolution having been given to all members entitled to vote.

15.2 In the event of the Association being dissolved, the amount that remains after such dissolution and the satisfaction of all debts and liabilities shall be transferred to the University of Adelaide, for expenditure on the Waite Arboretum only.

16. ALTERATION TO THE CONSTITUTION

This Constitution may be altered by resolution of a majority of three-quarters of members entitled to vote and who cast a vote in person or by proxy at a general meeting. Written notice of amendments shall be posted to all members entitled to vote at the same time as the notice of the meeting.

17. REQUIREMENTS OF THE PUBLIC FUND

The organisation must inform the Department responsible for the environment as soon as possible if:

- it changes its name or the name of its public fund; or
- there is any change to the membership of the management committee of the public fund; or
- there has been any departure from the model rules for public funds set out in the Guidelines to the Register of Environmental Organizations.

18. MINISTERIAL RULES

The organisation agrees to comply with any rules that the Treasurer and the Minister with responsibility for the environment may make to ensure that gifts made to the fund are only used for its principal purpose.

19. CONDUIT POLICY

Any allocation of funds or property to other persons or organizations will be made in accordance with the established purposes of the organisation and not be influenced by the preference of the donor.

20. WINDING-UP

In case of the winding-up of the Fund, any surplus assets are to be transferred to another fund with similar objectives that is on the Register of Environmental Organizations.

21. STATISTICAL INFORMATION

Statistical information requested by the Department on donations to the Public Fund will be provided within four months of the end of the financial year.

An audited financial statement for the organisation and its public fund will be supplied with the annual statistical return. The statement will provide information on the expenditure of public fund monies and the management of public fund assets.

22. RULES FOR THE PUBLIC FUND

22.1 The objective of the fund is to support the organization's environmental purpose.

22.2 Members of the public are to be invited to make gifts of money or property to the fund for the environmental purposes of the organisation.

22.3 Money from interest on donations, income derived from donated property, and money from the realisation of such property is to be deposited into the fund.

22.4 A separate bank account is to be opened to deposit money donated to the fund, including interest accruing thereon, and gifts to it are to be kept separate from other funds of the organisation.

22.5 Receipts are to be issued in the name of the fund and proper accounting records and procedures are to be kept and used for the fund.

22.6 The fund will be operated on a not-for-profit basis.

22.7 A committee of management of no fewer than three persons will administer the fund. The committee will be appointed by the organisation. A majority of the members of the committee are required to be 'responsible persons' as defined by the Guidelines to the Register of Environmental Organizations.

SPEAKER AND PANELLIST PROFILES

Philip Weinstein

Philip Weinstein is Professor of Ecosystem Health and Dean of Graduate Studies at the University of South Australia. He is a medical graduate of the University of Adelaide and Fellow of the Royal Australasian College of Public Health Medicine and was most recently Professor of Public and Environmental Health at the University of Queensland where he also led an environmental health research group. He was formerly the Head of School of Population Health at the University of Western Australia and Associate Dean Research at the Wellington School of Medicine, University of Otago.

Phil has over 200 publications on the environmental determinants of water-borne and mosquito-borne disease, and also led a major research programme on air quality and respiratory health through the Cooperative Research Centre for Asthma and Airways. He was a member of the Board of Review Editors for the Millennium Ecosystem Assessment and Co-Chair of the International Medical Geology Association, and remains an enthusiastic teacher. Phil's most recent research has focused on the value of maintaining biodiversity in suppressing the emergence of infectious disease epidemics in humans.

Sheryn Pitman

Sheryn Pitman manages the South Australian Green Infrastructure Project hosted by the Botanic Gardens of Adelaide, an evolution of the Sustainable Landscapes Project which began in 2004. This work brings together diverse stakeholders to integrate the planning and design of green spaces and water systems that underpin the health and sustainability of our towns and cities.

Sheryn has a multidisciplinary background in environmental and project management, education, research, writing and communication. With a Masters Degree in Environmental Studies she worked for seven years with Greening Australia engaging communities in landscape rehabilitation and habitat restoration. Prior to this she spent many years as a creative and technical writer including documentary film, television and radio and five years as a secondary school teacher.

Currently Sheryn is two thirds of the way through a PhD in Environmental Management with Professor Chris Daniels at UniSA.

Dr Kate Delaporte

Dr Kate Delaporte graduated from University of Adelaide with a BAgSc (Hons) and a Doctorate of Philosophy.

She was the 3rd Playford Trust Horticultural Scholar. In 1999-2000 she was awarded a Churchill Fellowship to study the use of Australian plants overseas.

Kate worked on the research and development of eucalypts, as the Postdoctoral Research Fellow the University of Adelaide's Ornamental Eucalypts Development Program with Professor Margaret Sedgley, in projects supported by the RIRDC, industry collaborators and the Playford Trust.

More recently, this work has been supported by Horticulture Australia Ltd, in collaboration with Industry and the University of Adelaide.

Sue O‟Keefe

Sue O'Keefe is an Associate Professor in the School of Economics at La Trobe University.

She is based at the University's Albury-Wodonga campus.

Her research interests focus on decision making and incentives and public policy, institutions and management, particularly in the context of water.

Ali Hassanli

Ali Hassanli is Associate Professor at Shiraz University, Iran and Adjunct Associate Professor at University of South Australia, School of Natural and Built Environments (NBE), Division of Information, Technology, Engineering and Environment (ITEE).

He is a lecturer and postgraduate student supervisor at Shiraz University and as a research fellow at UniSA.

Ali has 30 years international experience in academic institutions, water and agricultural industries. He has a long history of field experience in various water and soil projects involving research, monitoring, design, assessment and evaluation.

He is the author of 4 books and one chapter of a book and published 45 journal papers and presented at 42 conferences regionally, nationally and internationally.

Peter Levett

Capital Works Officer, City of Salisbury SA

Peter is a highly experienced public works practitioner. He has in excess of twenty 20 years' experience in major metropolitan Adelaide councils in civil and landscape construction and maintenance.

In his current role at City of Salisbury Peter administers a significant road surfacing program and other civil works. Peter has lead initiatives to achieve carbon reduction strategies and is active in cross council forums seeking improved industry standards in road surfacing.

In 2012 the Council Solutions procurement body recognised Peter for his role as an innovator.

Peter Young

Landscape Design Officer, City Of Salisbury, SA

Peter's early career was focussed on skatepark design and promotion of this form of recreation culminating in 2009 with a redevelopment masterplan for Canberra's Belconnen Skatepark to become Australia's largest.

During University of Adelaide studies in landscape architecture he worked with Taylor Cullity Lethean and credits a rigorous design ethos with this experience.

Since 2008 Peter has been employed at City of Salisbury working on a range of landscape and biodiversity projects.

Peter is a strong advocate for water sensitive urban design in local government.

Sean Connell

Sean Connell is Professor of Marine Biology at the University of Adelaide. He works to understand the effect of land and atmospheric change on coastal marine ecosystems.

Sean has shown how natural catchments positively affect the marine environment, how discharges cause habitat loss of seagrass and kelp habitats and what the possibility is of restoration.

Michael Leers

Michael Leers is currently the Coordinator Parks & Landscapes with the City of Fremantle.

Michael has been working in local government for more than 15 years. During this time his focus has been managing Public Open Space with particular attention to tree selection and establishment in the urban environment. He graduated from The University of Melbourne (B. App. Sci. Hort Honours) in 2000.

Michael is currently completing a Masters of Horticulture by Research with The University of Melbourne. His research and ongoing interest, is investigating factors which influence the establishment of street trees.

Dr Darren Peacock

Dr Darren Peacock is the Managing Director of Sociable Technology, an independent digital strategy consultancy based in Adelaide.

Darren works with government, cultural, educational and community organisations to help them plan and implement digital communication strategies and projects. He has twenty years' experience in planning and managing information and communication projects and services. His doctoral research explored how organisations innovate through their use of digital information and communication technologies.

Darren has a strong interest in heritage and the natural environment and serves on the Council of the National Trust of South Australia.

David Lawry

David Lawry is responsible for co-founding TREENET (Tree and Roadway Experimental and Educational Network) in 1997 with Dr Jennifer Gardner, curator of the Waite Arboretum.

With a Degree in Agricultural Science and a long horticultural history in the nursery and landscaping industry, David is a respected champion for the emerging science aimed at improving the establishment and retention of trees in urban settings, particularly street trees.

David doesn't consider himself a tree expert by any measure and maintains that the success of TREENET is entirely due to the support of the "real legends of arboriculture in Australia" and in the TREENET community "who are changing the way we go about our daily work as urban foresters".

David is a regular guest on talk-back radio and eagerly sought by print and television media to offer comment about tree issues.

In 2004, David initiated the "Avenues of Honour 1915-2015" project. In 2013 in his new role as co-director of TREENET David has a special focus driving and coordinating the project which will coincide with the Centenary of ANZAC in 2015.

Dave Williams

Dave Williams has been working in tree related industries for over 15 years. With a diverse range of qualifications and experience Dave has expertise in many aspects of tree management.

Dave began his career in the early 90's working in the Red Gum forests of southern NSW. After some time working as a tree feller for a mobile timber mill he decided to begin full time study.

Enrolling in a Bachelor of Science at the University of Melbourne Dave completed predominantly Ecology and Botany related subjects finishing his degree in 1996.

Following the Bachelor of Science and still at The University of Melbourne Dave enrolled in a Bachelor of Forest Science completing the degree with Honours in 2000. Dave's honours project was looking at nitrogen cycling in native forests.

Dr Greg Moore

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.

ENVIRONMENTAL CHANGE, DISEASE, AND BIODIVERSITY

Prof Phil Weinstein
School of Population Health, University of Queensland, Australia
Graduate Studies Centre, University of South Australia, Australia

For further reading about Phil Weinstein's subject matter refer to the following publications:

Elsevier Journal **Medical Hypotheses 76 (2011) 877-880**

Does biodiversity improve mental health in urban settings?

Julie Dean [a,*], Kate van Dooren [a], Philip Weinstein [a,b]

[a] School of Population Health, University of Queensland, Australia
[b] Graduate Studies Centre, University of South Australia, Australia

As published in proceedings of 6th International Conference and Workshop on the Built Environment in Developing Countries, 4-5 December 2012, Adelaide, Australia by University of South Australia

FROM GREY TO GREEN: LIFE SUPPORT FOR HUMAN HABITATS

Sheryn Pitman[1] and Martin Ely[2]
[1]Barbara Hardy Institute & School of Natural and Built Environments, University of South Australia, Adelaide, Australia
[1]Department of Environment, Water and Natural Resources, Adelaide, Australia
[2]Waite Arboretum, University of Adelaide, Adelaide, Australia

Introduction

Green Infrastructure (GI) is a systems-based approach to the design and function of our towns and cities which aims to secure the health, liveability and sustainability of present and future urban environments. By investing in Green Infrastructure we strengthen the resilience of towns and cities to respond to the major challenges of growth, health, climate change, biodiversity loss and water, energy and food security.

While GI has been interpreted in various ways, it is effectively described as the network of planted green spaces and water systems that deliver multiple environmental, social and economic values and services to urban communities. The focus of most GI thinking is directed towards urban environments in towns and cities because these are the places where an increasing majority of people live and where lack of 'green' can result in many problems. GI includes parks and reserves, backyards and gardens, waterways and wetlands, transport corridors and greenways, farms and orchards, squares and plazas, roof gardens and living walls, sports fields and cemeteries.

Throughout the world and particularly in industrialised countries, Green Infrastructure is being embraced as an important component in the development and redevelopment of urban environments. Without Green Infrastructure cities and towns risk becoming urban deserts in the sense of being hostile and barren places where people are disconnected from nature and from each other. A rapidly growing body of evidence supports the key role of Green Infrastructure in providing critical life support for human habitats.

Approach

Three main perspectives of Green Infrastructure have been identified in literature and in practice. They include an *Ecosystem services* approach in which GI delivers services and benefits similar to those delivered by natural processes (Daily 1997) a *Linked green spaces* approach whereby GI provides a healthy and sustainable alternative to the traditional 'grey' or engineering services-based infrastructure (Benedict and McMahon 2002) and a *Green engineering* approach in which GI is seen as a specialised form of engineering infrastructure that replaces conventional elements with 'green' elements that perform ecosystem service functions such as storm water harvesting, waste management and energy efficiency (Margolis and Robinson 2007). For example the City of Sydney labels energy trigeneration and a decentralised water networks as 'green infrastructure' responses to climate change (City of Sydney 2012).

The way of thinking most relevant to the work that needs to be done to create healthy and sustainable places to live and work integrates all three with emphasis on the *Linked green spaces* approach. Networks of plants and water systems deliver services and functions that urban environments require and provide a 'green' framework for sustainable living and development. Evidence of the importance of Green Infrastructure in urban environments has been gathered from studies and reports around the world. In order to consider the values and benefits we have grouped them: human health and well-being; water, air, soil and climate; climate change; biodiversity; food; and economics.)

Human Health and Well-being

Research over the last 20 years has investigated connections between contact with nature and human health and well-being. Health and well-being are defined in the broadest sense to mean not only the absence of disease, but a state of physical, mental and social well-being. Abraham et al. (2010) reviewed the health promoting aspects of GI, which include physical well-being, mental well-being and social well-being. There is a clear link between the built environment (including landscapes) physical activity and health (Kent, Thompson et al. 2011). Physical activity is promoted by access to nearby green spaces and well designed 'walkable streets' (Giles-Corti, Broomhall et al. 2005).

A large body of research supports the psychological benefits of contact with nature. Early work undertaken in the United States by Rachel and Stephen Kaplan (Kaplan and Kaplan 1989) included research into the 'restorative effects of nature' and found that the natural environment can foster people's wellbeing and their ability to function effectively. Steven Kaplan 's Attention Restoration Theory proposes that contact with nature engages our 'involuntary attention' giving our 'directed attention' (voluntary attention) the opportunity to rest, thus helping overcome the mental fatigue associated with continual directed attention (Kaplan 1995).

One of the best known studies of the restorative powers of nature was conducted by Roger Ulrich who showed that abdominal surgical patients had shorter post-operative hospital stays when accommodated in a room looking out on a stand of trees (Ulrich 1984). Positive connections with nature have been found in a range of studies including reduction of ADHD symptoms (Faber Taylor and Kuo 2009), reduced crime in inner city neighbourhoods (Kuo and Sullivan 2001) and strengthening of a sense of community (Kuo, Sulivan et al. 1998). At the University of Illinois Landscape and Human Health Laboratory, Kuo, Sullivan and others are researching inner-city residents' responses to trees and other vegetation and the ways in which the physical and psychological health of individuals and communities can be improved with enhanced access to nearby nature.

Importantly, more attractive urban green spaces can enhance opportunities for social interaction, fostering community ties and a sense of identity that has been found to be fundamental to human health and well-being (Maas, van Dillen et al. 2009a). According to Armstrong and Leyden, urban parks and other public places can enhance social integration if they facilitate social contacts, exchange, collective work, community building, empowerment, social networks and mutual trust (Armstrong 2000; Leyden 2003). Trees and greenery increase the attractiveness of places for people, in turn promoting community socialisation and passive surveillance, which can reduce crime and increase personal safety (Coley, Kuo et al. 1997; Kuo and Sullivan 2001; Kuo 2003).

A particular focus is on the role of Green Infrastructure in dealing with the emerging physical and mental health epidemic in Australian children (Malkin 2011). Writer Richard Louv in his book *Last child in the Woods* has coined the term Nature-Deficit Disorder to describe the effects on children of enforced alienation from nature. These effects include a number of behavioural issues including diminished use of the senses, attention difficulties and higher rates of physical and emotional illnesses. Louv argues that sensationalist media coverage and paranoid parents have literally 'scared children straight out of the woods and fields' while promoting a litigious culture of fear that favours 'safe' regimented sports over imaginative play (Louv 2005). Two recent studies by Planet Ark have investigated the changing role of children's play, and the health and well-being benefits to children of contact with nature. Rises in childhood obesity and mental health issues have been linked to dramatic lifestyle changes in the last 20 years. The 2011 study, *Climbing Trees*, found a dramatic shift in childhood play activity in the space of one generation (Planet Ark 2011). For example 64% of parents said that they climbed trees when young, compared with only 19% of their children. A 2012 study, *Planting Trees*, investigated the intellectual, psychological, physical and mental health benefits of contact with nature for children (Planet Ark 2012). This study reviewed local and international research in this field and revealed an emerging body of evidence that 'contact with nature during childhood could have a significant role to play in both the prevention and management of certain physical and mental health problems, and in forming environmentally responsible attitudes in future adulthood'.

Water, Air, Soil and Climate

Green Infrastructure provides a wide range of natural functions, often called 'ecosystem services', including cleaner water and air, healthier soils and more amenable urban climate and microclimates (Millennium Ecosystem Assessment 2003). Issues of global climate change and local extended drought have further highlighted the need to address a range of environmental issues, including making better use of Green Infrastructure in the public realm.

Vegetation cover plays an important role in the natural water cycle, modifying rainfall inflows, soil infiltration and groundwater recharge, and patterns of surface runoff (Xiao, McPherson et al. 2006). Urbanisation, however, has seen the natural water cycle replaced by the ‘urban water cycle’, with extensive impervious surface and highly efficient drainage systems dramatically increasing the quantity but reducing the quality of urban storm water runoff. This has negative impacts on the ‘receiving’ aquatic ecosystems, while removing a valuable water resource from the city (Wong 2006). Water Sensitive Urban Design (WSUD) emerged during the 1990s as a new paradigm for the more sustainable management of the water cycle in the urban landscape (Argue 2004). Green Infrastructure can play a vital role in helping to restore or better replicate the natural water cycle in urban areas. In particular, vegetated WSUD systems contribute in a number of ways: canopy interception (Xiao et al. 2006); soil infiltration and storage (Bartens, Day et al. 2008); improved storm water runoff quality through biofiltration processes (Denman, May et al. 2011); and flood damage control (Lull and Sopper 1969; Craul 1992).

More recently the concept of Water Sensitive Urban Design has been expanded to embrace the many ways in which water and more appropriate water management can enhance the ‘liveability’ and ‘resilience’ of our cities (Living Victoria Ministerial Advisory Council 2011). Along with the provision of safe, secure, affordable water supplies, WSUD supports green landscapes that significantly enhance urban amenity, help to combat the impacts of the urban heat island effect, improve the health of urban waterways and provide opportunities for active and passive recreation. The emerging concept of the Water Sensitive City has three main ‘pillars’: Cities as Water Supply Catchments; Cities Providing Ecosystem Services; and Cities Comprising Water Sensitive Communities (Wong 2011).

An ecosystem service provided by urban trees and other vegetation is that of improving air quality in cities. Plants have several natural functions: they remove atmospheric pollutants; oxygenate the air; and absorb carbon dioxide through photosynthesis (Brack 2002; Nowak, Crane et al. 2006). Studies show that gaseous pollutants are absorbed by leaves and either metabolized or transferred to the soil by decay of leaf litter, which may be particularly important in streets with high traffic volumes (Nowak 1994; Scott, McPherson et al. 1998). The leaves of trees also collect and trap airborne particles on their surfaces. The most significant impacts on air quality, however, are through reductions in carbon dioxide and atmospheric pollutants (Nowak, Stevens et al. 2002).

A valuable benefit of Green Infrastructure to cities is that of climate modification, especially temperature reduction. The ‘urban heat island effect’ (UHI) refers to the phenomenon where the air and surface temperatures of cities are typically much higher than surrounding rural or vegetated areas, especially at night (Bornstein 1968; Rosenfeld, Akbari et al. 1998). Temperatures in cities on cloudless days have been found to be as much as 12^0C warmer than surrounding rural areas (Oke 1987). In Melbourne, researchers have reported a mean UHI of around 2 to 4°C and as high as 7°C depending on the location, time of the year and time of day (Morris and Simmonds 2000; Coutts, Beringer et al. 2010).

The urban heat island effect results from the storage and re-radiation of heat by building materials and paved surfaces and from urban heat sources such as the burning of fuel for heating and transportation. Lack of vegetation in cities also contributes to the urban heat island effect. Reduced tree cover leads to both a reduction in shading of surfaces and a reduction in transpiration cooling by tree canopies in comparison with rural areas (Federer 1976). Cities are also drier than surrounding areas, as the natural ground surfaces are frequently replaced with asphalt and concrete surfaces which create higher surface temperatures and reduce evaporation from the soil that may otherwise cool the surface (Miller 1980).

The urban heat island is now recognised as contributing to health risks in large cities such as Melbourne (Loughnan 2009). Urban heat island effects contribute to increased morbidity/mortality rates in ‘heat wave’ events, especially among the aged (Loughnan, Nicholls et al. 2008; Loughnan, Nicholls et al. 2010; Tapper 2010). In Melbourne on days over 30 degrees C the risk of heat related morbidity and mortality of people over 64 years of age increases significantly. Evidence suggests that buildings with little or no surrounding vegetation are at a higher risk of heat related morbidity (Loughnan, Nicholls et al. 2008; Loughnan, Nicholls et al. 2010; Tapper 2010).

One method of mitigating extreme summer temperatures in the urban areas is to adopt the ‘cool cities’ strategy (Luber 2008). Trees and other vegetation modify urban microclimates and help reduce the urban heat island effect through two major natural mechanisms: temperature reduction through shading of urban surfaces from solar radiation, and evapotranspiration which has a cooling and humidifying effect on the air

(McPherson, Herrington et al. 1988; McPherson 1994; Akbari, Pomerantz et al. 2001; Pokorny 2001; Georgi and Zafiiridiadis 2006).

Climate Change

It is now widely accepted that human activities are contributing to global climate change due to increased levels of greenhouse gases in the atmosphere (Thom, Cane et al. 2009). Green Infrastructure, especially urban trees, can play an important role in the two responses to climate change: climate change mitigation, and climate change adaptation.

While climate change mitigation strategies often include reduction of CO^2 emissions through increased use of public transport and energy efficiency (ClimateWorks 2010), urban trees can contribute to net reductions in atmospheric CO^2 through carbon sequestration and storage and also through avoided CO^2 emissions due to building energy savings. Moore (2006) estimated that the 100,000 public trees in Melbourne would sequester about one million tonnes of carbon. In 2000, Brisbane's residential tree cover was estimated to absorb the equivalent amount of CO^2 emitted by 30,000 cars per year and to cool surface temperatures in the relatively mild month of October 1999 by up to 5 degrees Celsius (Plant 2006). Such performance can result in reduced demand for air-conditioning energy, leading to a reduction in carbon emissions from power stations (McPherson and Simpson 2001). It is important to balance these reductions against CO^2 released by the decomposition of dead trees and vegetable matter, and emissions produced in the management of urban trees (McPherson, Simpson et al. 2009). Similarly, the potential of urban trees for carbon storage should not be overstated, as street trees are often short lived and small in stature (Nowak and Crane 2002; McPherson 2008).

Another benefit of Green Infrastructure is in assisting towns and cities to adapt to climate change (Shaw, Colley et al. 2007; Thom, Cane et al. 2009). While the impacts of climate change are difficult to predict and vary from region to region, likely effects in Australia include increased temperatures, reduced rainfall and extended periods of drought, increased bushfire risks and more extreme weather events such as storms and flooding (Suppiah, Preston et al. 2006). Climate change adaptation strategies include cooling of buildings and houses and cooling of the outdoor surrounds (Nice 2012). Urban trees assist in reducing temperatures in cities through shading, evapotranspiration and wind speed modification (Akbari, Pomerantz et al. 2001). They can also play a role in relation to other climate change impacts such as providing shelter from predicted extreme weather events, reducing runoff and flooding from extreme weather events and improving air quality in increasingly dense cities (McPherson, Simpson et al. 2006).

Biodiversity

Biodiversity plays a fundamental role in the functioning of ecosystems and their ability to deliver long-term ecosystem services. Worldwide biodiversity loss is therefore an area of great concern (Groombridge and Jenkins 2002). Links between biodiversity and human health and well-being have been well documented (Tzoulas, Korpela et al. 2007) and loss of biodiversity impacts the quality of essential life support systems, the incidence and spread of infectious diseases and the potential for developing new treatments and medicines (Chivian and Bernstein 2004). On a sociological level, urban nature and biodiversity in cities contributes to human sense of place, identity and psychological well-being (Horwitz, Lindsay et al. 2001).

Urban habitats and species are often considered to be less important than their wild or agricultural counterparts. Biodiversity, however, can be higher in cities than surrounding rural areas and comprise a rich and diverse ranges of plants and animals, often occurring as unusual or unique communities (Angold, Sadler et al. 2006). It may not always be possible to preserve large areas of natural habitat within cities, however Green Infrastructure elements can act as reserves of species biodiversity within urban areas (Alvey 2006). Green Infrastructure provides a means of enhancing biodiversity and reducing habitat fragmentation in urban areas (EC 2012). While urban street trees are often exotic species, it has been demonstrated that exotic trees do contribute to attracting wildlife (Tait, Daniels et al. 2005; Young and Johnson 2005). Street trees are utilised by a variety of bird species including native birds and especially those well adapted to the urban habitat (Tzilkowski, Wakeley et al. 1986; Fernandez-Juricic 2000). Kazemi et al. (2009) compared the biodiversity of six bioretention basins with other urban green spaces in Melbourne. Greater species diversity was found in the bioretention basins compared with garden and lawn or grassed green spaces. They concluded that the incorporation of vegetated WSUD systems in urban streets and green spaces has the potential to enhance urban biodiversity. Importantly, Green Infrastructure can enhance 'connectivity' through the provision of biodiversity corridors and other linkages, a key aspect of the ecosystems approach to conservation (Vimal, Mathevet et al. 2011).

Food

Food security is an issue of growing concern. Green Infrastructure and urban food are intimately related through the perceived needs to retain productive agricultural land on the urban fringe and to integrate food production into urban areas. Urban food production takes place in many ways and has been found to result in a wide range of human health and well-being outcomes.

The importance of preserving urban agriculture, including market gardens and farming, on the urban fringe is increasingly being recognised (Paster 2004; Mason and Knowd 2010). There is concern that suburban development is alienating viable agricultural lands in close proximity to urban centres (Sinclair 2009). Issues of climate change and sustainable development, especially the impacts of oil based transportation, highlight the benefits of retaining productive agricultural land in close proximity to cities (Knight and Riggs 2010; Pearson, Pearson et al. 2010). Urban or community based agriculture, and the consumption of local produce, have gained popularity in recent years as evidenced by the increase in farmers' markets and community gardens. Key health and well-being benefits include access to healthy food options and the opportunity to undertake physical activity implicated in growing and producing food (Mason and Knowd 2010). In a comprehensive study of the community garden movement in the United Kingdom, Holland (2004) p.1 concluded that while some gardens played a strategic role in food production, all gardens were *'based in a sense of community, with participation and involvement being particularly strong features'.* Bartolomei et al. (2003) examined the social and health-promoting role of a community garden scheme in a high-rise public housing estate in Sydney. The findings confirm the role of community gardens in strengthening social interaction. The scheme was associated with increased opportunities for local residents to socialise and develop vital cross-cultural ties in a very diverse environment.

Economics

Placing a monetary value on Green Infrastructure, while potentially controversial, does help in the communication of benefits to stakeholders and the community, and can be fed directly into the policy decision making process (Vandermeulen, Verspecht et al. 2011).

Research has shown that Green Infrastructure can enhance the economic attractiveness of cities (Whitehead et al. (2005). A number of studies by Kathleen Wolf have investigated the effect of trees and landscaping on the commercial vitality of a range of US shopping centres, as measured by factors such as willingness to pay higher prices and travel further distances to shop in centres with trees and landscaping (Wolf 2004; Wolf 2004a; Wolf 2005). Survey findings indicated that preference ratings increased with the presence of trees, indicating a clear valuing of the trees in terms of their amenity and visual quality. The presence of trees also appeared to influence consumer perceptions of businesses and the quality of their products. Respondents indicated a willingness to travel greater distances, visit more often and pay more for parking at locations with trees. These surveys also revealed a higher estimation of the value of business districts with trees (the amenity margin associated with trees ranging from 12% for large cities to 19% for small cities).

Researchers have also investigated the effects of street trees and nearby open space or water features on residential property values. For example a survey by the Real Estate Institute of Queensland in 2004 found that the value of homes in leafy streets were up to 30% higher than others in the same suburb (Plant 2006). While some of these studies include anecdotal information, a number of recent studies have employed more sophisticated 'hedonic pricing' techniques. Hedonic analysis uses the sale prices of comparable properties to isolate increases in market value due to specific variables, such as the presence of street trees. A recent study by Donovan and Butry (2010) used a hedonic price model to simultaneously estimate the effects of street trees on the sales price and the time-on-market (TOM) of houses in Portland, Oregon. On average, street trees added US$8870 to the sales price and reduced TOM by 1.7 days. In addition, the researchers found that the benefits of street trees spill over to neighbouring houses. Another recent study by Sander et al. (2010) used hedonic property price modelling to estimate the value of the urban tree cover in Minnesota. The results showed that a 10 percent increase in tree cover within 100 metres increases average home sale price by $1371 (0.48%) and within 250 metres by $836 (0.29%). The researchers concluded that the results suggest significant positive effects due to neighbourhood tree cover, for instance the shading and aesthetic quality of tree-lined streets, indicating that tree cover does provide positive neighbourhood externalities.

Another field of study is attempting to quantify the net economic values of the ecosystem services provided by Green Infrastructure. There has been considerable research effort in the US aimed at quantifying the economic benefits of urban trees, with the rationale of providing compelling evidence to encourage local and other authorities to strengthen tree planting programs. Benefits measured include air pollution reduction, storm water runoff reduction, direct carbon capture, indirect emission reduction from the cooling effects of tree shade and higher sales prices of houses in leafy streets (Coder 1996; MacDonald 1996; Hewett 2002; Plant 2012). One example is a 1996 study of storm water management costs, demonstrating that urban trees provided storm water management benefits valued at US$15.4 million in Milwaukee, Wisconsin, and US$122 million in Austin, Texas, by reducing the need for constructing additional retention, detention and treatment capacity (MacDonald 1996). A recent study at the Australian National University estimated that the trees in Canberra have an annual economic value of more than $23 million through energy reduction, pollution mitigation and storm water reductions (Killy, Brack et al. 2008).

A University of Adelaide study estimated the gross annual benefits from a typical medium sized street tree in Adelaide (Killicoat, Puzio et al. 2002). A four year old tree was estimated to generate a gross annual benefit of approximately $171 per tree, consisting of energy savings due to reduced air conditioning costs, air quality improvements, storm water management, aesthetics and other benefits. Stringer revisited this estimate in a 2007 paper and concluded that, with more adequate data and computer simulations, the gross benefits would actually be significantly higher (Stringer 2007). In a follow up paper in 2009 the annual benefits for a typical Adelaide street tree were recalculated at approximately $424 per tree (Brindal and Stringer 2009).

Economic modelling is now commonly being used in the United States to quantify the economic benefits generated by urban trees (USDA Forest Service 2005). The United States Department of Agriculture (USDA) Forest Service provides online tools such as i-Tree which allow communities to estimate the net economic benefits generated by their urban tree populations (McPherson, Simpson et al. 2005). The model can quantify benefits such as energy conservation, air quality improvement, CO^2 reduction, storm water control and property value increases. Such economic modelling has been applied in a number of United States cities including Davis in California, Milwaukee, Minneapolis, Pittsburgh, Houston and New York (Maco and McPherson 2003). Importantly, these analyses are assisting cities like New York, Los Angeles, Portland, Sacramento and Baltimore to justify investments in major urban greening projects that address declining urban tree cover, increasing population and urban climate change.

Since i-Tree was first introduced in 2006, the tools have been adapted for application to regional Australian conditions. The i-Tree STRATUM was trialled by the University of Melbourne in a study of two Melbourne city councils: the central City of Melbourne, and the newer outer suburban City of Hume (NGIA 2011). Modelling shows that for the environmental benefits selected (carbon sequestration, water retention, energy saving, aesthetics and air pollution removal) the population of street trees in two suburbs of the City of Melbourne provides ecosystem services equivalent to approximately $1 million dollars, and approximately $1.5 million dollars in the City of Hume. On an individual scale, the trees in the City of Melbourne provide ecosystem services valued at $163 per tree, and in Hume at $89 per tree.

Rationale and guiding principles

Green Infrastructure is a systems based approach to the design and function of our towns and cities. Green Infrastructure underpins the health, liveability and sustainability of present and future urban environments. By investing in Green Infrastructure we strengthen the resilience of towns and cities to respond to major challenges of population and urban growth, health, climate change, biodiversity loss and water, energy and food security.

To achieve the potential benefits of Green Infrastructure it must be embraced as an integral element of the urban landscape. Government, industry and community sectors require a thorough understanding of the benefits as well as a robust capacity for design, development and maintenance. Planning and investment in Green Infrastructure needs to be guided by the following five principles:

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

Process in South Australia

The value and importance of Green Infrastructure are becoming understood and appreciated within government and industry organisations. A collaborative partnership managed by the Botanic Gardens of Adelaide, Department of Environment, Water and Natural Resources (DEWNR) involves Renewal SA (Urban Renewal Authority), State Department of Planning, Transport and Infrastructure (DPTI), and the Adelaide and Mt Lofty Ranges Natural Resources Management Board (AMLR NRM).

The Green Infrastructure project has undertaken a strategic planning process to identify the pathways and processes necessary to achieve effective, long-term change in the way Green Infrastructure is perceived, designed and managed. This process has involved consultation with government, industry and community stakeholders in the diverse fields of health, land and water management, sustainability and climate change, design, education, transport, recreation, land development, policy and planning.

Through research and development of a scientific evidence base, working closely with policy, planning and development agencies, identifying and assisting exemplar projects, developing resources and raising awareness throughout the community, the project aims to facilitate the incorporation of GI within an integrated approach to urban design and development and to improve capacity for its development and maintenance in South Australia.

Conclusion

Connected networks of green spaces and water systems underpin the functionality of towns and cities and impact directly on community health and well-being, liveability and sustainability. Plants and water form the basis for life and in an increasingly urbanised world, Green Infrastructure is essential in providing life support to towns and cities, the primary human habitats of the future.

The ultimate success of Green Infrastructure as a new 'paradigm' requires: recognition of its values and benefits, by the whole community and at the highest strategic levels; capacity building in the institutions and organizations involved in implementing Green Infrastructure in its different forms; and incorporating Green Infrastructure as an essential, rather than optional, component in the urban development process.

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DO EUCALYPTS HAVE A PLACE IN THE URBAN FOREST OF TODAY AND TOMORROW?

How can we make this iconic Australian tree genus into a happy suburbanite?

Are 'designer trees' the answer?

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Introduction

The Eucalypts (genera Eucalyptus, Corymbia and Angophora) contain unique flora with over 700 species found throughout Australia (and its closest northern neighbours) and represent one of Australia's greatest floral icons. Eucalypts play a vital role in all Australia's ecosystems providing habitat for native birds, insects and animals. There are a great number of species that are seldom seen in cultivation, with ornamental flowers, leaves, buds, and fruit.

The majority of eucalypts available in the Australian nursery sector are grown from seed, with a small number of grafted varieties mainly from the Corymbia genus. Breeding and development programs will enable a wider range of ornamental eucalypts to become available to the Australian nursery and garden sector, with "design" of new hybrids and selection of superior forms. All selected forms must be clonally propagated to ensure genetic integrity, however, clonal propagation (including cutting production, grafting and tissue culture) is difficult in most eucalypts and can be genotype dependant. As published research to date has focused on a limited number of eucalypts, there exists a large gap in knowledge as to how the majority of ornamental species will respond to clonal propagation.

How can we make this iconic Australian tree genus into a happy suburbanite? Are „designer trees" the answer?

This paper will discuss the University of Adelaide's Ornamental Eucalypt Development Program, what we have done, what we are doing, why we are doing it and what we will do in the future, to address these questions.

An example of a long term breeding program with lots of collaboration, funding, hard work and passion, that is starting to bear fruit.

The University of Adelaide's Ornamental Eucalypt Development Program (OEDP) commenced in 1996 with PhD research by Dr Kate Delaporte. Her PhD studies looked at aspects of the development of eucalypts for ornamental horticulture, and generated hundreds of interspecific hybrids. These hybrids were planted in the Laidlaw Plantation, a two hectare site at Urrbrae, South Australia, which now contains over 800 putative hybrid eucalypt genotypes, as well as around 350 individuals from 30 different species planted for breeding purposes, and is a significant germplasm resource for the OEDP.

Research and development of ornamental eucalypts continued from 2000, with projects funded by RIRDC (Publication No 04/125, No 08/018 and No 12/120), the Playford Memorial Trust, with additional support from the Laidlaw Family, the Frank and Hilda Perry Trust and the SA State Government.

The RIRDC funded programs sought to breed and select superior forms for further development, They focussed on breeding new varieties for the Australian cut flower market, investigation of the selected lines for their suitability for cut flower production (vase life assessments), propagation (trials including cutting propagation and grafting) and general production capabilities. The general criteria for cut flower varieties include desirable flower colour and presentation, floriferousness, tree architecture, response to production methods and economic propagation.

During that time, Humphris Nursery teamed up with the OEDP to undertake investigations into the top 10 selections for suitability for propagation by grafting. This required an examination of potential rootstock species and grafting methods, as the OEDP varieties at that time were from the *Symphyomyrtus Bisectaria* group of eucalypts, and far different from the *Corymbia* types then available. The selection process was long and difficult, but yielded results in 2012 with the first release of two OEDP varieties, Nullarbor Lime and Nullarbor Rose. These two varieties are derived from crosses between dry land species from Western

Australia, *E. macrocarpa*, *E. pyriformis* and *E. youngiana*, and have retained the glaucous wax of the male parent *E. macrocarpa* and the more upright habits of the female parents. The varieties are grafted onto selected seed grown rootstocks to make them more adaptable to a range of climates and soil types. It has been a slow and expensive process, with 5 years of research and development to find the best rootstock and grafting conditions.

All reports from these projects can be sourced from RIRDC (http://www.rirdc.gov.au/publications).

More recently, from 2010-2013, Horticulture Australia Pty Ltd and three Australian Nurseries provided support for the OEDP to gather base line knowledge about ornamental eucalypts, to underpin further development (Project NY09023).

The HAL Project investigated the reproductive biology of eucalypts and aimed to optimise propagation methods to enable a future eucalypt breeding programme. The partners in this project were Yuruga Nursery (Walkamin, FNQ) to investigate tissue culture, Narromine Transplants (Narromine, NSW) to investigate cutting production, and Humphris Nursery (Mooroolbark, VIC) to investigate grafting.

A number of gaps in the knowledge base underpinning the development of ornamental eucalypts for horticulture were identified. Very little information exists on the relationship between climate and reproductive development, and also very little information on stigma receptivity and pollen viability for any species outside of the forestry industry. Over 100 individual plants from 42 species and eight hybrid populations were used during this study. All plants are located at the Waite Campus, Laidlaw Plantation, or the Waite Arboretum, Urrbrae, South Australia.

This project sought to address some of the gaps by investigating aspects of reproductive biology, phenology, and clonal propagation:

1. How well does pollen of these species survive in storage, and what temperatures are optimal for pollen germination? Results indicate that pollen remains viable after storage, but viability decreases from 70% (2 years storage) to 40% (10 years storage); pollen will germinate well between 10-35°C, and will remain viable after storage for 21 days between 10 and 35°C.

2. How many days after anthesis (cap fall and pollen shed) do the stigmas become receptive? Previous research suggests anywhere from 0 to 10 days, but what is it for ornamental species? Results were inconclusive; generally pollen applied 5 to 8 days after anthesis will produce the most seed, but it varies with species.

3. How does the phenology of a species/hybrid change and how do flower buds develop, and is there an effect of environmental conditions, such as temperature, day length or rainfall, on the timing of flowering? Phenology charts were produced for most of the species and hybrids within this trial, however, with only 2 and a half years to gather data, significant correlations between climate and phenology were not found. The study needs many more years' worth of data, and a wider range of species and locations before a true picture will emerge (but it is important to start somewhere!).

4. What is the effect of flower size and genetic relatedness on "crossability"? If we cross *E. macrocarpa* with *C. ficifolia*, what are the chances that will produce viable seed? And what about the actual technique - can we use the methods developed by the forestry industry to make pollinations more efficient? This part of the program crossed many different species, with different size flowers, and compared the two most often used techniques – classical pollination and the "One Stop Pollination" method. The likelihood of seed being produced was dependant on flower size, genetic relatedness and technique, and varied considerably between species. While close crosses generally produced seed, of particular note are the successful intergeneric crosses between *Corymbia* species and *Eucalyptus* species. Seed was produced from crosses between *C. calophylla* x *C. ficifolia* (genus *Corymbia*) and *E. miniata* (genus *Eucalyptus* subgenus *Eudesmia*), *C. citriodora* and *E. rhodantha* (genus *Eucalyptus* subgenus *Symphyomyrtus*), *C. citriodora* and *E. miniata* (genus *Eucalyptus* subgenus *Eudesmia*), and *E. conveniens* x *E. tetragona* (genus *Eucalyptus* subgenus *Eudesmia*) with *C. ficifolia* (genus *Corymbia*), however this seed has not yet been germinated.

5. Can ornamental eucalypts be propagated clonally in an economic and reliable way? The Project partners investigated grafting, cuttings and tissue culture. In brief, propagation by grafting and cuttings showed limited success, while propagation by tissue culture was highly successful for particular lines.

Grafting identified ongoing issues with scion:rootstock combination incompatibility, rootstock variability (clonal rootstocks produced through tissue culture may alleviate this issue), pre- and post- graft environmental conditions, scion size and maturity, and the time and expense of producing plants through grafting.

Cutting propagation was investigated by cuttings derived from mature trees (coppice) and from seedlings. Eucalypts are extremely difficult to propagate by cuttings, it is highly genotype and maturity dependant. Some success was achieved, but results were very dependent on maturity of tissue and the genotype.

Propagation via tissue culture was successfully achieved, essentially using micro cutting methods developed from the forestry industry, where lines are established in culture from seed. This proved highly successful, with good initiation and multiplication from MOST seeds. Rooting and de-flasking proved much more difficult, and establishment even harder. Every step is genotype dependant and requires investigation to determine optimal conditions. *Corymbia* seed lines where much more suited to the tissue culture methods used than the *Symphyomyrtus Bisectaria* lines. Differences in optimal methods are apparent at all stages of the process, including the media & conditions needed for multiplication and rooting, and for deflasking and establishment.

The other problem encountered with tissue culture is selection. If the plants are initiated into culture from seed, how do we select them for their ornamental characteristics? The first selection step is the actual initiation in culture – the line must multiply, root and survive acclimatisation in sufficient numbers to be economically viable. Then, plants are set out to field trials to wait for flowering. This is most likely to take 5 years from seed, and for that whole time the lines must be maintained in tissue culture, with regular subculturing to maintain the health of the plantlets. If you are very lucky, you might get a line that flowers early, say, within 2 and a half years from seed. And it might have a flower colour that you are looking for. And it might have a habit that is desirable for home gardens and urban forestry. This is when you would need to start large scale field trials, in pots and in ground, to more thoroughly determine the characters of the new variety and make sure it is stable.

The OEDP and collaborators are very happy to say that they were lucky that such a line was found, and we are progressing this little wonder plant through the field testing process as we speak.

The full report from this project is available from Horticulture Australia Ltd (http://www.horticulture.com.au/)

But what has all this got to do with 'Designer Trees' and eucalypts in suburbia?

In Australia, our external environment is full of eucalypts. In the country areas, there are areas of remnant native vegetation, mixing with farmland with planted trees, some endemic, some from other parts of Australia. They are part of the landscape, and give a sense of place. In urban environments, the trees are fewer, and less comfortable in their surrounds. Often, they are majestic large trees, memories of a time prior to white settlement, but now causing conflicting emotions and opinions as humans try to reconcile a huge tree and its importance for habitat, air quality and human happiness with the problems of sheer size, water-seeking roots, limb dropping, 'messy' flowers, and resident wildlife. Sometimes, the trees are the result of well-meaning Council planners and enthusiastic gardeners, planted 30-40 years ago, untried and untested, possibly with unrealistic expectations as to their growth and impact on the environment. These trees are now creating problems and ill feeling in the community.

Ironically, conversations along the lines of "we need to plant more eucalypt trees in our urban environment" precede "My neighbour planted a eucalypt and it's too big and its shading/dropping leaves on my garden". How can these conflicting opinions be reconciled? Are 'designer trees' the answer?

Take a set of characters that a tree should have: the height, the architecture, the canopy density, the vigour. Sometimes, the flower and leaf should be considered too. Now, look at all of the species (eucalypts in this case) and identify which species have what characters. Mix that with a good understanding of the relationships between species, the reproductive biology and genetic relatedness; develop a program to cross breed different species with desirable characters, and (hopefully) produce a new plant with the characters you want. For example, *Corymbia maculata* grows well in the eastern states, has a good upright habit, minimal limb drop (reportedly), but the bark, while attractive, is grey. *C. aparrerinja* on the other hand, has a glorious white trunk, but is a spreading tree from the sub tropics. Can the two be bred together, to result in an upright tree with a white trunk that grows well in most locations in Australia? In this case yes, however, the process of breeding new trees isn't quick; it can take 5-10 years to produce the new tree and road test it, and get it ready for wide spread use.

It's easy to see that many of the trees, be they eucalypt or other, in our urban forests are in decline, or will be soon, from age, inappropriateness, climate change, disease. For example, the City of Melbourne Urban Forest Strategy 2012-2032 reports "Modelling shows that within the next ten years, 23% of our current tree population will be at the end of their useful lives and within twenty years this figure will have reached 39%." (City of Melbourne Urban Forest Strategy Revised Draft, September 2012).

These trees will need to be replaced, and the choice of what will be used to increase, renew and revitalise the Urban Forest across Australia becomes important. The same varieties and species that are currently planted could be planted again, or, we could look to a new generation of trees. Designer eucalypts could find an increased presence in our cities, and if they are more suited, planting them could take precedence over exotic species.

Armed with over 15 years of experience, the OEDP is about to embark on a new breeding program, to 'design' the 'right eucalypt for the right place'. We aim to develop a range of trees that are suitable to a range of climates, or for more specific ones; that have the shape, size, flowering, trunk colour, that is sought by designers; that will be disease resistant, low maintenance, non-invasive and 'safer'; that will increase city biodiversity and keep humans happy and healthy. It's a long term project and will not succeed without input from nurseries, advanced tree producers, landscape architects, councils and arborists, so expect to hear more from the OEDP soon.

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HEALTHY AGING AND THE IMPORTANCE OF WATER

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For further reading about Sue O'Keefe's subject matter refer to the following publications:

"Water management and healthy ageing in rural Australia: economic, social and cultural considerations." Environment and Behaviour, accepted 31 July 2013 (in press)

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RECYCLED WASTEWATER FOR PARKLAND PLANT IRRIGATION AND SUSTAINABILITY MEASURES

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Abstract

Recycled water is one of the main water resources with substantial contribution to increase the security of future water supplies. Scientific and technical studies are required to maximize this contribution through developing water recycling opportunities and reuses particularly for green space irrigation to provide environmentally, socially and economically sustainable environments. The use of municipal recycled water for green space plants is a valuable attempt to use the easily available water resources but it requires a monitoring system to mitigate the possible inverse impacts on the soil, plants and water systems. Variables such as climate, irrigation methods and frequency, plant species and soil can have a profound effect on the sensitivities of plants to salts and toxicity. Soil drainage, irrigation application rate, water quality, rainfall characteristics and plant canopy shade can influence the long-term effects of salinity, and toxic effects of chemical compounds on the vegetation health. It is, therefore, important to have information specific to each individual plant species, as well as information on all the above-variables, specific to each locality, in order to properly plan and manage water requirements of specific landscapes. In this paper the main potential inverse impacts of reuse of recycled water for irrigation is discussed and Adelaide parklands as a case study is briefly reviewed.

Keywords: Recycled wastewater, reuse wastewater, Irrigation, Adelaide Parklands

Introduction

Rapid urbanization and industrialization have increased the pressure on limited existing fresh water to meet the growing needs for food production and keeping environment in a healthy condition . Utilizing efficient irrigation systems and using alternative sources of water, such as recycled wastewater, to meet the growing demands would be a positive response to this concern (Hassanli et al, 2010). The majority of urban water supplies for irrigation are used to maintain vegetation health, appearance and municipal amenity (Nouri et al, 2012). Climate change is also threatening Australian urban water supplies through increasing evapotranspiration and decreasing precipitation. The most severe climate change impact is expected in the southern and eastern regions of Australia (Collett and Henry, 2011).Increasing water use efficiency and also water efficiency in urban landscapes are achieved by supplying only the amount of water that the plants require to maintain healthiness and aesthetic appearance. The water demand of urban landscapes is quite different from agricultural crops and turf grasses due to the specific conditions in urban green spaces (Costello et al., 2000).The use of recycled wastewater has been identified as a potential sustainable irrigation practice and one of the management approaches. Recycled wastewater may potentially contain pathogens and levels of chemicals deleterious to vegetation and the environment. Although low concentrations of certain chemicals may not have immediate and obvious toxic effects on vegetation or the structure of the soil, bioaccumulation may occur, causing long-term chronic effects(Salgot et al., 2006). Continued irrigation using recycled water, in long term could exceed the soil's adsorption capacity for salts (Nable et al., 1997). Particularly during dry seasons when there are few rainfall events which could leach the salts from the soil. Soil structure can be affected by excess sodium in irrigation water (Hassanli et al, 2007) which reduces soil aeration and water filtration rates. This, in turn, leads to water logging, excess runoff and restricted root growth. In this paper the potential inverse impact of reuse of recycled wastewater for landscape irrigation is discussed and Adelaide parkland as a case study would be reviewed.

Salinity and general toxic effects of recycled wastewater

The level of salt accumulation within the soil depends on a number of different factors: physical and chemical characteristics of the soil; annual precipitation; evapotranspiration; the annual water application and most importantly, the concentration of salts in the irrigation water(Lazarova and Bahri, 2005).When the levels of dissolved salts are high in the soil, additional energy is required for plants to take up water from this medium. The increased osmotic pressure of salty soil water is the reason for this higher demand on the plant's energy resources. Symptoms of salinity stress are similar in most plant species. These symptoms include leaf scorching, (Fig. 1) mottling or shedding and twig dieback in angiosperms (Azza Mazher et al., 2007).

Fig.1: Toxic effects of salinity on leaves(Las Pilitas Nursery, n.d.)

Each plant species has a specific salinity tolerance level above which the growth and productivity of the plant is affected (Azza Mazher et al., 2007). The salt tolerance variation of different plants and a typical crop response to salinity are shown in Fig. 2.

(a) (b)

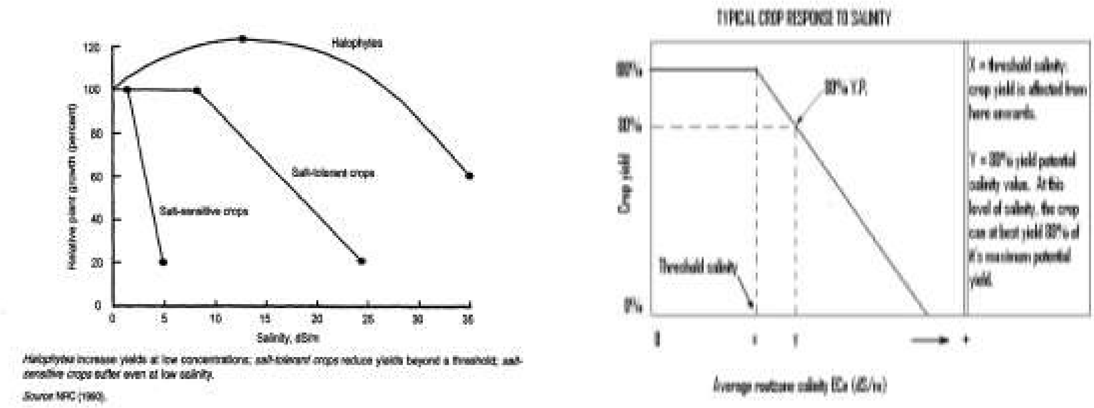

Figure 2. Salt tolerance variation of different plants (a) and a typical crop response to salinity (b)

Halophytes which occur naturally in saline conditions are often not as badly affected as non-halophytes which may die more readily under excessively saline conditions. Environmental conditions may also have an effect on each species' response to salinity. In general excessive salinity inhibits vegetative and reproductive growth and sometimes induces changes to plant morphology and anatomy. The most common toxic elements in wastewater are Sodium (Na), Chloride (Cl) and Boron (B). For landscaping and agricultural purposes, the most important components are those chemical elements that have an effect on the growth of plants and the structure and permeability of the soil (Pedrero et al., 2010). Different soils, drainage, irrigation methods and amount of shade will influence the long-term effects of salinity, and chemical elements on the vegetation. Ongoing foliar irrigation can lead to toxic levels of Na, Cl and B in the leaves of plants. Although all species respond differently to foliar irrigation application, generally, the amount of foliar damage has been in direct proportion to the frequency of sprinkler treatment (Devitt et al., 2003). An excess of any irrigation can cause water logging and secondary salinity.

Toxic effects of sodium on plants

Figure3. Necrotic patches caused by sodium toxicity on a grape vine (PIRSA, n.d.)

Soil with excess sodium may exhibit changes in soil structure. These changes could reduce the rate of water infiltration and aeration of the soil. This in turn reduces the water available for uptake by plants and could also increase the amount of sodium taken up in the water by plants. The toxic effects of sodium accumulation in plants are evidenced by leaf mottling and necrotic patches (Fig.3) on the leaves (Stevens et al., 2008). High levels of sodium also cause damage to the root cells and can interfere with the photosynthetic processes of the plant. Woody plants are particularly vulnerable to the toxic effects of sodium as the symptoms are not seen for some time (Stevens et al., 2008) since the excess sodium accumulates in the roots and trunk. The uptake of essential macronutrients by the plant can also be affected when high levels of sodium are present in the soil (Stevens et al., 2008).

Toxic effects of chloride on plants

Figure4. Evidence of chloride toxicity in an aspen (Goodrich and Jacobi, 2007/2008)

Chloride is an essential micro-nutrient required in small quantities by all plants (Stevens et al., 2008). It is also one of the most common phytotoxins which is typically absorbed through the roots of the plant. It can also be absorbed through the plant leaves, and this speeds up the rate of toxic accumulation of the ion (Lazarova and Bahri, 2005). The toxicity level of chloride ions will be specific to each plant or plant group, and should be considered on an individual basis. Visible symptoms of chloride toxicity usually appear before those of sodium or boron (Azza Mazher et al., 2007). These symptoms include marginal chlorosis of the older leaves, followed by extensive leaf scorching, wilting and eventually defoliation (Fig.4). An indirect effect of excessive chloride levels is the prevention of absorption of essential nutrients such as nitrate and phosphates (Stevens et al., 2008).

Toxic effects of boron on plants

Boron is an element that is actually required for good plant growth (Lazarova and Bahri,2005). The range between acceptable and toxic levels of Boron is quite small (Stevens et al., 2008) and plants respond differently to specific levels of boron. These toxic levels do not often occur in arable soil, making it necessary to ensure the water used has minimal levels of boron. Plants are able to withstand higher soil boron levels in soils with a pH range of 7.5-9.5 (Stevens et al., 2008). Another factor influencing increased uptake of boron is the method of irrigation. The visible symptoms of toxic levels of boron are typically leaf burn and necrotic patches as shown in Fig.5. Other less typical symptoms are yield reductions (Stevens et al., 2008).

Effects of water logging

Figure5. Necrotic effects of boron on apple tree leaves (University of Georgia Plant Pathology Archive, n.d.)

Water logging has different effects on different plant species. The effects also vary depending on the salinity of the soil and water surrounding the plant. Kozlowski (1997) explains in great detail multiple physical and physiological effects of water logging on woody plants. Plant growth, reproduction and photosynthetic capabilities are all adversely affected by water logging. In addition, plants that have experienced water logging become more prone to drought because of their shallow and small roots (Kozlowski, 1997). The increased water uptake under waterlogged conditions also increases the salt ion uptake in the plant. Water logging also affects plant aeration and root penetration and root distribution. Visual evidence of water logging can be leaf tip burn as shown in Fig. 6.

Glenelg wastewater for Adelaide parklands

Urban land scapes impact on the microclimate, hydrological cycle, biodiversity, water quality, air pollution, removing significant amounts of pollutants such as nitrogen, phosphorus and fine sediments and in general have environmental, social and economic benefits. There is currently a lack of adequate information specific to the Adelaide Park Lands vegetation, their tolerance to salinity and toxicity and their threshold levels. There is little research to investigate water requirements of mixed vegetation in urban landscapes such as plantings in the parkland systems. However, currently a research using WOCULS approach for estimating parkland plants water requirement is curing out at UniSA. Adelaide Park Lands, with an area of 720 ha are a core component of Adelaide, brings environmental, social, cultural and financial benefits for the people of Adelaide. The average main element concentrations in the Glenelg recycled wastewater is given in Table 2. The variation of concentration of these elements, coupled with irrigation application rate and the other management measures are important for long term sustainable irrigation management.

Figure6. Leaf damage as a result of water logging (Manitoba Agriculture Food and Rural Initiatives,n.d.)

Table 2. Annual average concentration of some main elements in Glenelg recycled wastewater (REM et al., 2008)

	Chloride (mg/l)	Boron (mg/l)	Sodium (mg/l)	SAR	Total N (mg/l)	Total P (mg/l)	EC (dS/m)
Annualaverage	389	0.281	261	7.50	15.8	6.74	1.8

The annual average salt concentration in the Glenelg recycled wastewater is nearly 1.8dSm^{-1}. Although the salinity variation in usual irrigation water is expected to vary up to 3 dS/m, irrigation with Glenelg recycled wastewater with an annual application rate of 4500m^{3}ha^{-1} would cause annual accumulation of nearly 9 tha^{-1} salts to the soil. In the lack of efficient irrigation management salinity build up hazard would be problematic in the long term. Toxicity often accompanies or complicates a salinity or infiltration problem although it may appear even when salinity is low. The toxic ions sodium and chloride can also be absorbed directly into the plant. In cases where the toxicity problem is not too severe, relatively minor changes in farm cultural practices can minimize the impact. An alternative water supply may be available to blend with a poorer supply to lower the hazard from the low quality water (Ayers and Westcot, 1994). A good indicator of sodium tolerance would be the presence of low sodium content in the plant leaves, in combination with high potassium content in the roots, stems and leaves (Adrover et al., 2008). Plant species that have high tissue calcium content in their leaves and stems would also be sodium-tolerant as calcium has been shown to neutralise the deleterious effects of various salts (Kozlowski, 1997).Typical toxicity symptoms are leaf burn, scorch and dead tissue along the outside edges of leaves in contrast to symptoms of chloride toxicity which normally occur initially at the extreme leaf tip. The average sodium level in the Glenelg recycled wastewater is 261mgl^{-1} and the amount of SAR is 7 (REM and SRHS, 2007). However, the sodium concentration in usual irrigation water is expected to be 0-920 mgl^{-1}. This shows that the sodium concentration in the Glenelg recycled wastewater is considerably below the maximum allowable level. However, it does not mean that accumulation of this toxic ion in the long term without considerable attention to sustainable irrigation management would not be a hazard for Adelaide Park Land plants, particularly for those that are sensitive to sodium. Wu et al. (1995) gathered experimental evidence from a number of landscape plants and suggests that plants with high concentrations of tissue calcium exhibit tolerance to chloride. Therefore, chloride-tolerance is positively correlated to tissue calcium percentages. Not much research has been done on Australian landscape plants and it is important to have knowledge specific to each plant species, before assuming chloride tolerance.

Chloride toxicity Boron toxicity management

Tolerances to chloride are not nearly so well documented as crop tolerances to salinity. Chloride moves readily with the soil-water, is taken up by the crop, and accumulates in the leaves. If exceeds the tolerance of the crop, injury symptoms develop such as leaf burn or drying of leaf tissue. With sensitive crops, the symptoms occur when leaves accumulate from 0.3 to 1.0 % chloride on a dry weight basis. Many tree crops, for example, begin to show injury above 0.3 % chloride. Chloride toxicity can occur by direct leaf absorption through leaves wet during overhead sprinkler irrigation. (Ayers and Westcot, 1994). Toxic levels of boron are usually related to soil types associated with low rainfall areas. As with sodium and chloride, boron-tolerance is specific to individual species and water application method. Research suggests that boron tolerance is at a genetic and cellular level (Nable et al., 1997). For example, differences in phloem mobility result in different accumulations of boron in the leaves, fruit and cambial tissue of a plant (Nable et al., 1997). It is therefore difficult to identify boron-tolerant plants from any physiological attribute. The allowable level of boron in the irrigation water is between 0-2 mgl^{-1}. The level of boron in the class A Glenelg recycled wastewater is 0.4 mgl^{-1} (REM and SRHS, 2007). Boron therefore is not a concern in the Glenelg recycled wastewater at least in the short term.

Conclusion

A wide variety of plants are used in the Adelaide Park Lands, each with a specific tolerance for high levels of salinity, sodium, chloride and boron. This further complicates the task of providing the correct amount of water without causing toxic levels of any of the above mentioned elements. It is important, therefore, to provide irrigation water that has salt concentrations suitable to a large number of plant species (Wu et al., 2001). Using recycled wastewater is a sustainable option for irrigation of the Adelaide Park Lands. It is however important to maintain a healthy and diverse collection of plants within the parklands in order to achieve one of the goals of creating habitat for native fauna. To this end, it is important to understand the nutrient requirements and characteristics for each species found within the parklands and to manage the care of the parklands accordingly. The amount of nutrient loadings using recycled water should be taken into consideration by monitoring the amount of nutrients are loaded by recycled water and are taken up by the plants. Previous reports have developed adaptive management frameworks designed to address the potential impacts of using recycled wastewater from Glenelg Wastewater Treatment Plant. A plant's salt tolerance is variable depending on the climate, weather, genetic variation, soil health, texture and structure and irrigations methods and frequency (Wu et al., 2001). Investigation undertook in a study (Hassanli and Kazemi, 2012) indicates that the average level of three main plant toxic elements, sodium, chloride and boron is lower than the maximum allowable level recommended in the guidelines in Water Quality for Agriculture developed by FAO (Ayers and Westcot, 1994). The average Na^+ and Cl^- level in the Glenelg recycled in 2005 was 242 and 364 mgl^{-1}, respectively (REM and SRHS, 2007). This shows that the Na^+ and Cl^- concentration in the Glenelg recycled wastewater is below the maximum allowable level. However, it does not mean that accumulation of these two toxic ions in the long term without considerable attention to sustainable irrigation management would not be a hazard for the Adelaide Park Land plants particularly those that are sensitive to toxicity of these elements. Findings suggest that further research would be needed to clarify the benefits of the irrigation of urban green spaces by recycled water and improve irrigation management to mitigate the possible inverse impacts of recycled water for a sustainable environment to ensure having a healthy plant, soil and water system across the Adelaide Parklands.

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COUNCIL VERGES AS THE NEXT WETLAND THE CITY OF SALISBURY AND TREENET WORKING TOGETHER

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Abstract

This paper details water sensitive urban design (WSUD) in practice in the City of Salisbury including the TREENET inlet system.

In collaboration with Uni SA and TREENET, the City of Salisbury is planning and implementing a range of research projects to provide evidence required to support the adoption of the technologies as standard practice for the city engineers and arborists.

The demands for onsite storm water retention, the need to defer capital expenditure on kerb and channel replacement and the much needed regeneration of an aging urban forest provided the incentive for Salisbury Council investigate putting WSUD to the test. It is anticipated that there will be significant savings in expenditure on repairing uplifted kerbs and footpaths as the root systems are naturally redirected away from this infrastructure in response to the relocation of water resources to the driest and thirstiest zone currently in the urban environment, the curiously named universal "nature strip".

Introduction

The City of Salisbury (CoS) is located in Adelaide's northern suburbs about 25 kilometres from the Adelaide GPO and extending from the shores of Gulf St Vincent to the Para escarpment and the foothills of the Mt Lofty Ranges. With an estimated population of 130,000 people and encompassing an area of 158km2, the region enjoys a typical Mediterranean climate, having cool, wet winters and warm to hot dry summers.

City of Salisbury's largest asset is its road network. The requirement to maintain this important network is more than asphalt and kerbing, it is the management of water which collects and flows through this network. Street Trees are a large investment for Council in provision of streetscape amenity, moderate local climate conditions, and frame the presentation of residential homes.

Within older residential areas the existing stormwater systems tend to be overland systems that are beginning to show signs of stress. Concerns regarding elevated predicted and current climate conditions have motivated alternate investment to reduce stresses upon aging infrastructure.

As urban density increases through Greenfield and Brownfield developments the available area for street trees to be planted reduces. Urban densification further reduces permeable surfaces, reduces the soil's ability to provide soil moisture levels viable for street trees to grow, maintain health and reach maturity. Service provider's infrastructure further reduces areas in which street tree placements can be considered viable.

Council is actively working towards future proofing these systems with simple solutions to create sustainable outcomes for the benefit of residents and council. These outcomes address issues regarding increased storm water volumes, ponding of storm water, reducing leaf litter debris, improving overall urban permeability, moderating soil moisture levels, passive irrigation of street trees and increased street tree vitality.

City Overview

The City is predominantly a residential area but also has substantial industrial, commercial and rural areas. Total land area is 161 square kilometres, including Adelaide's second commercial airport and RAAF Edinburgh, many parks, reserves, walking trails and wetlands. Horticultural enterprises (mainly vegetable growing) are located on the western fringes of the urban development. Significant growth over the previous two decades has been fuelled by factors including major urban development projects, industrial investment, a burgeoning defence sector and strong growth in tertiary education. General Motors Holden's Elizabeth vehicle assembly plant is located in an adjoining suburb.

Salisbury has gained international recognition for its integrated water management practices, and particularly stormwater harvesting and aquifer storage and recovery. It has eight stormwater harvesting sites supported by 150km of purple pipe network.

Figure 1. Location within Australia

Figure 2. Location within Adelaide

The estimated resident population of the City of Salisbury was 132,500 in 2011, increasing steadily over the previous two census periods.

The 30-year plan for greater Adelaide identifies a key target of 169,000 extra residents for greater northern suburbs; whilst a large portion of this is achievable via green field development the remainder implies densification of existing urban areas. Greater urban density reduces private garden spaces in size and impervious areas are greatly increased, thus permeable areas for rain water to infiltrate the soil are reduced. These impervious zones shed stormwater at far greater rates than the permeable zones and increase the total storm water volumes within council infrastructure.

Existing older residential area stormwater systems (dating from 1940s to 1980s) tend to be an overland system upon flat grades that have historically had drainage problems. Sub-division and redevelopment of older residential blocks increases local catchment volumes; stressing these overland systems. High intensity rain events have shown that localised flooding occurs in these areas; causing the need for emergency relief work, property damage in extreme events and ultimately discontent with residents. Concerns regarding elevated predicted and current climate conditions have motivated alternate investment to reduce stresses upon aging infrastructure.

New housing developments are required to accommodate predicted stormwater requirements without impacting downstream stormwater networks1. The Development Plan requires an open space provision of 0.4 hectare within 500m safe walking distance of every house2. However, this open space provision is not protected from becoming the developments stormwater detention basin. In which larger rain events turns the residents playspace, kick and catch area or a reserve turned into a temporary pond with tree plantings.

CoS has embarked upon housing development projects including 15% affordable housing3. Incorporated into the streetscape design are rain garden bays designed to capture rain events up to 1 in 5 ARI4 with adjacent native plantings of grasses, shrubs, groundcovers and street trees. The overflow from these rain gardens is plumbed into the storm water network to discharge into the onsite detention basin. A permanent water body surrounded by walking tracks with seating and connected to Councils Green Trail linear path network for passive recreation.

[1] Salisbury Development Plan: Land Division Principles of Development Control 1.i pg 16

[2] Salisbury Development Plan: Public Open Space Principles of Development Control 1.b pg 60

[3] Sustainable Futures: The Living City 3.1 pg 50

[4] Minister's Specification SA 78AA September 2003 *On-Site Retention of Stormwater*

Soils and Climate

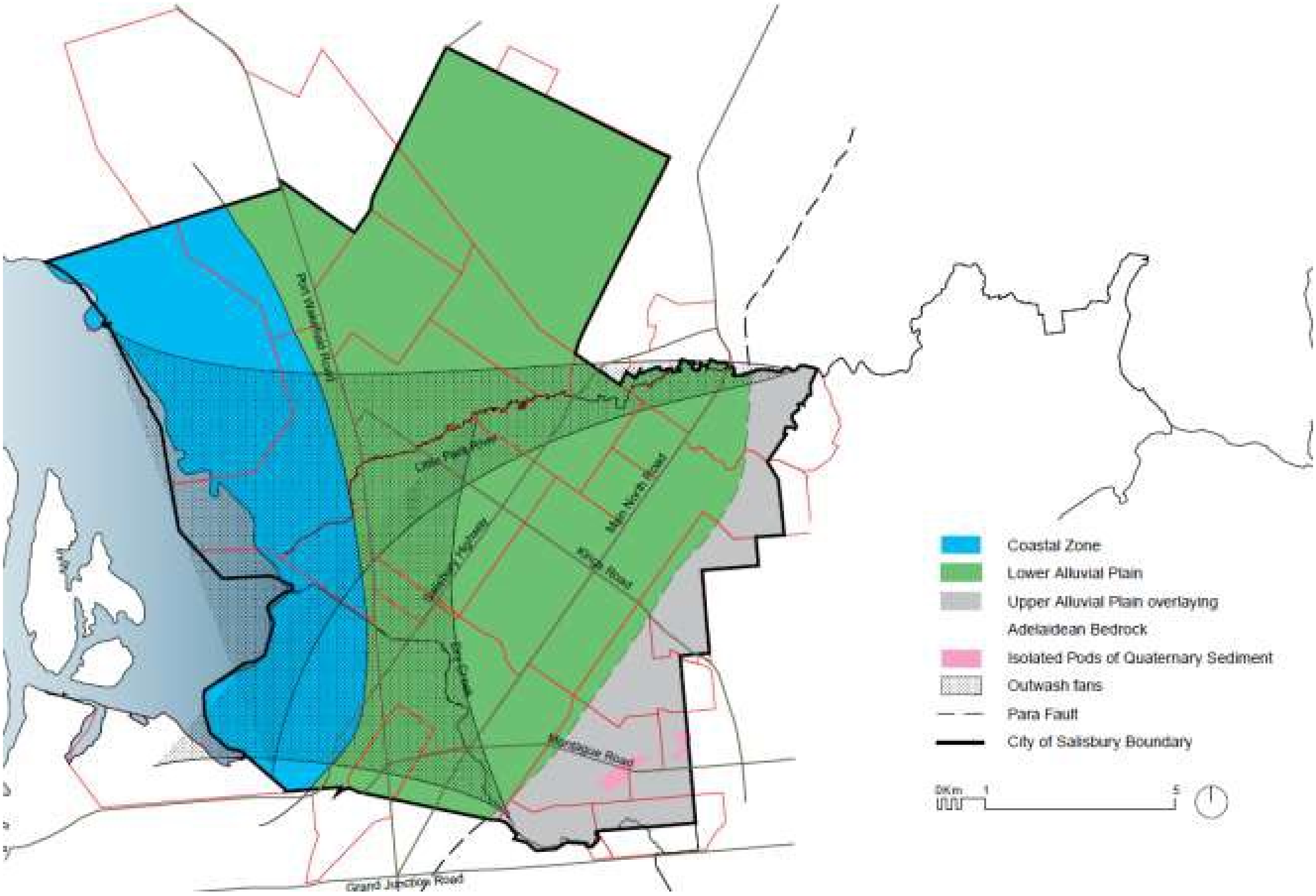


Figure 3. Physiographic Regions of Salisbury

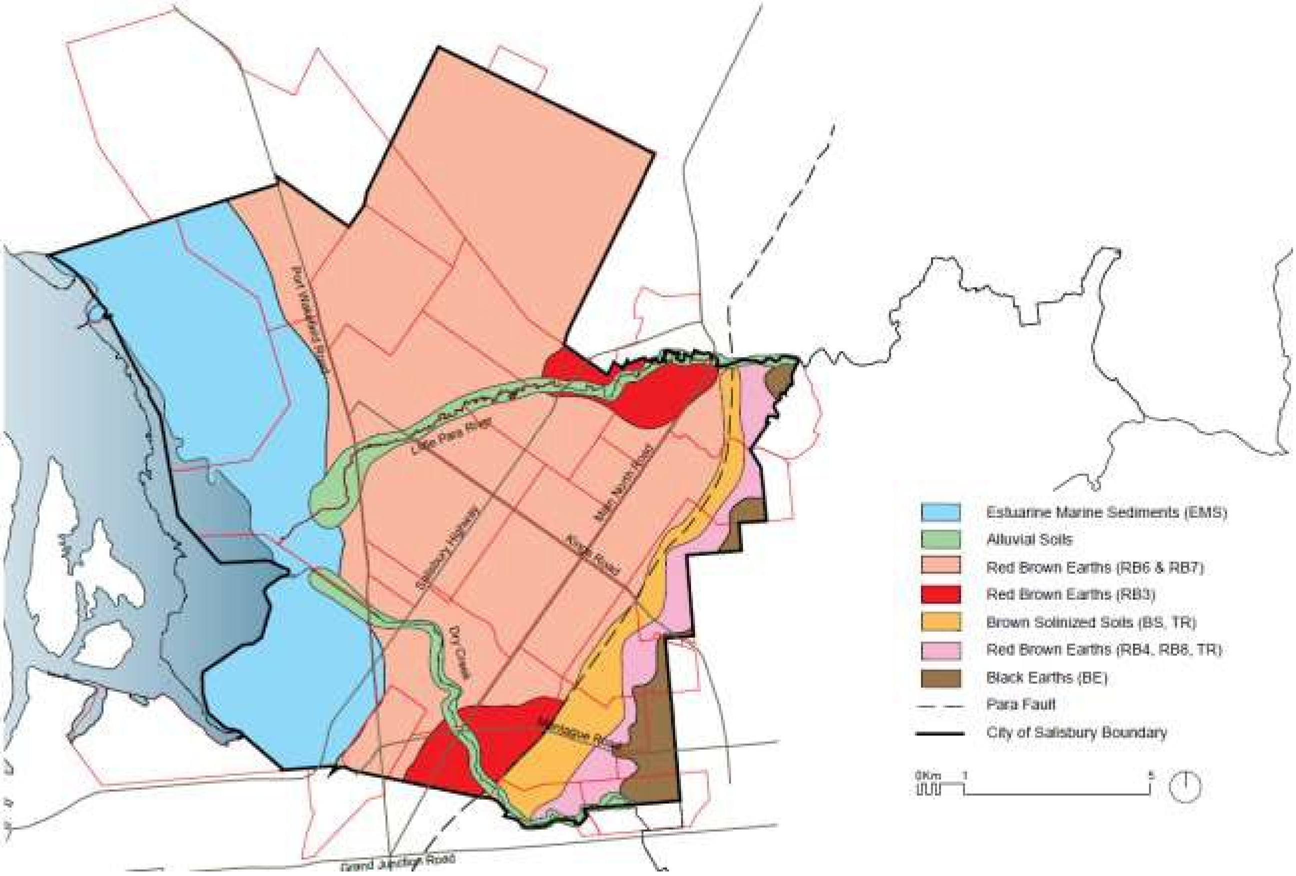


Figure 4. Soil Associations

Soil types across the Salisbury district, referred to as The Lower Alluvial Plain, are characterised by Red-Brown Earths (RB). These soils are considered to be the most productive within the Adelaide Plains which allows for a wide ranging street tree palette. There are a number of variations of Red Brown Earths which are found within the lower alluvial plains of Salisbury including RB3, RB6 and RB7.

RB3 comprises a sandy or silty grey to red-brown A horizon over a well-developed red clay B horizon, with varying lime content into the C horizon. The RB3 soils are generally deeper and contain finer textured sediments than other RB soils. The RB6 and RB7 show little variation between horizons. RB6 soils form towards the lower reaches of the outwash fans and are often affected by the high water tables and salinity levels. RB7 soils form closer to streams and creeks resulting in larger granular material within the A and B horizons5.

Rainfall varies significantly across the Salisbury area, decreasing significantly closer to the coast. While the average annual precipitation for the Salisbury region is 460.50 mm, some areas of the upper alluvial plain will receive as much as 550 mm, while areas along the coast will receive much less. South Australia experiences droughts during which time average rainfall can be reduced significantly, and available rainfall and soil moisture become important factors in determining plant survival. The budget for the Salisbury region shows a long period of deficit where evaporation exceeds precipitation, followed by a short period of recharge (where moisture is retained within the soil) during June and July. During this time, the soil does not become saturated (saturation point is the amount of water that the soil can hold before run-off begins). The use period (the period when the available soil moisture from the recharge period is being used through evaporation and transpiration) is very short, less than one month, before deficit begins again in early August6.

[5] City Landscape Plan 2.2.3 Soil Associations. City of Salisbury

[6] City Landscape Plan 2.2.4 Weather, Climate and Soil Moisture Budgets. City of Salisbury

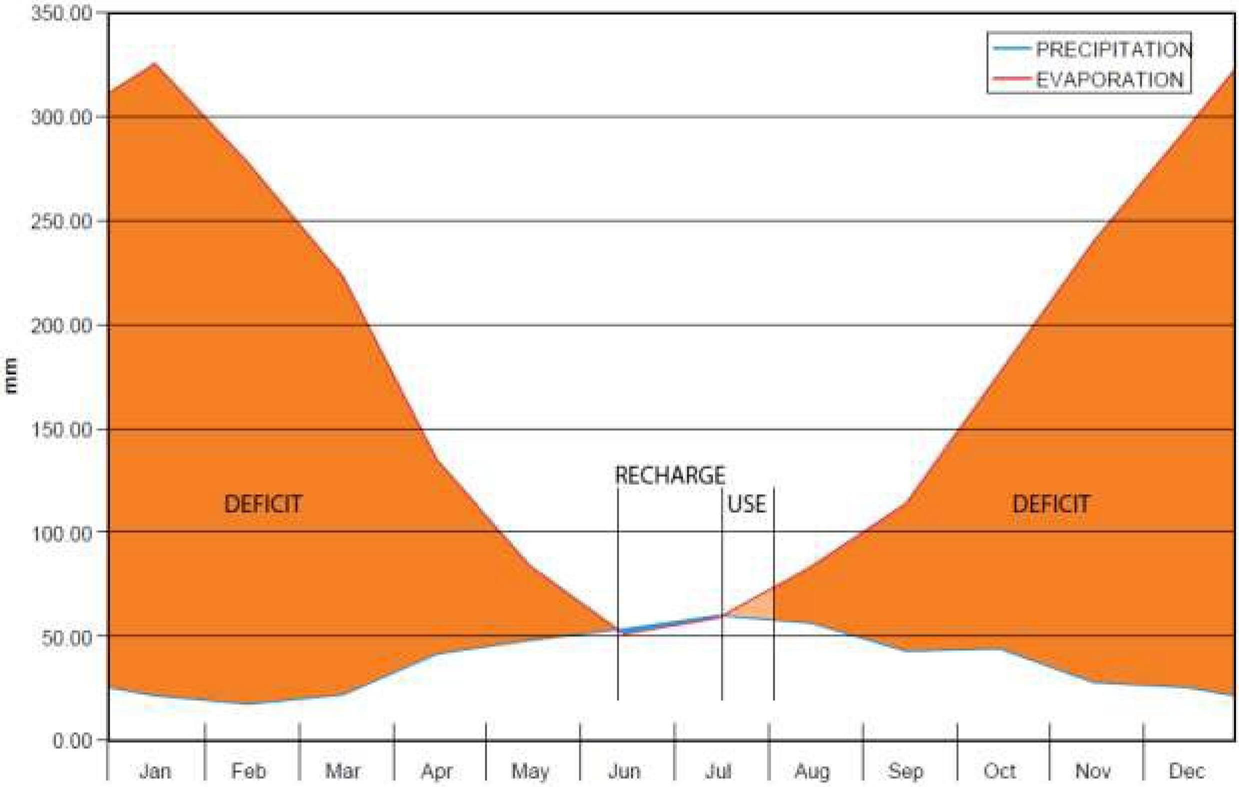


Figure 5. Soil Moisture Budget

The council verge as the next wetland

In an average year 160 gigalitres (160 GL) of water flow down Adelaide's gutters and into Gulf St Vincent. This run off carries a high load of nutrients and sediment which are destroying the marine environment. The recommendations from the Adelaide Coastal Waters Study final report (ACWS Nov 2007) are for an urgent reduction in the volumes of storm water discharge to bring about a 75% reduction in nitrates, a 50% load reduction in particulate matter, as well as reduced flows of organic and mineral toxicants to coastal waters. The State Government in its 2004 Waterproofing Adelaide blueprint set a target of 20 GL of storm water reuse by 2025 which is only a 12% reduction on current outputs. Urban sprawl and infill will only add to the torrent of storm water so there is little chance that any improvement in the marine environment as envisaged in the ACWS can be achieved. No doubt there will be increasing adoption of "wetland" technologies to clean some of this polluted rainwater before sending it on to the ocean or preferably to the aquifer. However this is a very capital intensive end of pipe strategy suited to a few locations remote from the source where land is available. What Adelaide needs are new, at source, low cost, readily implemented systems that deliver multiple benefits to the community and the environment. Taking water from the gutters and putting it into the subsoil adjacent to street trees is an option currently using WSUD.

The demands for onsite storm water retention, the need to defer capital expenditure on kerb replacement and the much needed regeneration of an aging urban forest provided the incentive for Council to put localised WSUD to the test. It is anticipated that there will be significant savings in expenditure on repairing uplifted kerbs and footpaths as tree roots are naturally redirected away from this infrastructure in response to the relocation of water resources to the driest and thirstiest zone currently in the urban environment, the Council verge.

Considering soil and climate conditions localised detailed stormwater data and soil infiltration rates were raised as critical success factors to designing WSUD alternatives. Infiltration can be maximised through designing the sumps with greatest surface contact area with surrounding soils. The floor area of the sump is the most likely to allow infiltration due to gravity and soil porosity, whilst the side walls of the sump allow horizontal infiltration. Yet the amount of horizontal infiltration is reliant upon the local soil hydraulic conductivity. The side wall is however the most likely point where adjacent tree roots are able to access available soil moisture. By maximising contact surface area is to allow the sumps to catch first flush rainfall and once saturation is achieved the infiltration rate is maximised to drain remaining ponded water within the kerb. This increased amount of moisture taken up by surrounding soils increases the amount of soil moisture available to street trees thus recharging soil moisture volumes.

Trees provide additional significant benefits other than simply providing an alternative for storm water and pollutant discharge to the marine environment. The direct influence of trees on climate and hydrology are standout advantages. Trees are very efficient solar powered pumps, capable of returning hundreds of litres of water a day to the atmosphere. In transpiring all that water, trees are giant evaporative coolers and combine this with shading and controlling air movement to reduce the temperature of the city and suburbs conservatively by 4 deg C.

Trees and infrastructure have been in conflict in the urban environment for centuries and the competition is over space and water. Impermeable pavements, kerbs and gutters conspire to deny trees these vital resources. In response tree roots follow moisture gradients produced at the interface between soil and concrete often damaging these same elements of infrastructure in the process. Another factor is that the primary source of water for many street trees are well watered front gardens which are accessed by shallow roots, lifting the footpath and producing trip hazards requiring expensive remediation. The placement of an inlet in the kerb midway between street trees can divert storm water from the gutter to a trench or cistern in the nature strip. This sets up a moisture gradient in the verge creating a preferential root pathway running parallel to the roadway and away from the infrastructure.

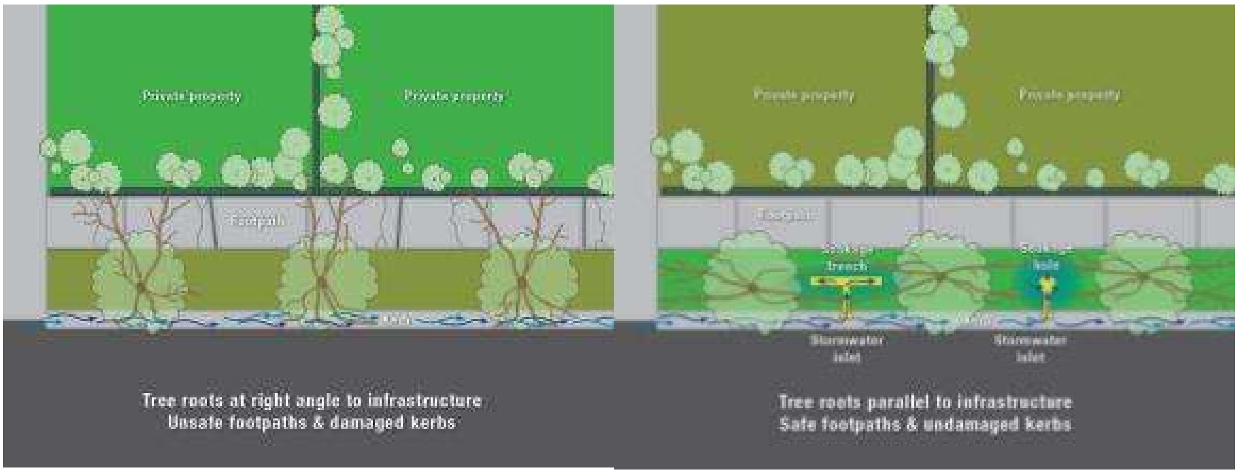


Figure 6. Street profile using water sensitive design in a verge application

The problem with most systems designed to take water from the gutter is that they also direct sediment, leaves, and other gross pollutants into the system eventually clogging them and reducing the infiltration capacity of the soil in the verge. The TREENET inlet has been successful in separating the majority of these components from the first flush stream which carries the soluble heavy metals and nutrients into a trench or cistern at the back of the kerb. The oldest installation (September 2010 Oxford Street Unley) is flowing freely after 3 years and no maintenance except for normal street sweeping activities.

However, the design of the "back end", the hole in the ground that receives the water from the inlet, is very much the subject of current research. The principal requirements are that it has sufficient capacity to accept all of the most polluted first flush component and that it is accessible to tree roots for extraction of the captured water. A hole or trench of at least half a cubic meter is backfilled with a no fines aggregate and a standard 90 mm stormwater pipe conveys the stormwater from the back of the TREENET inlet in the kerb to this simple "cistern". The open nature of the aggregate allows rapid uptake of the first flush water and retains it until it has infiltrated into the surrounding subsoil, principally at depth. Infiltration rates into the surrounding soil are improved as the roots decompact the verge and biopores are created following the senescence and replacement of fine absorption roots. One simple system installed at the Waite Institute in 2011 is illustrated below. It is called the "black hole" because it has been backfilled with approximately .75 m3 of recycled water filtration residue from Happy Valley reservoir which contains a high proportion of pollutant absorbing activated carbon. This waste material has a high water uptake of 40% and so this "black hole" can take 300 litres of first flush stormwater, lock up the soluble pollutants, and then make available the nutrient component for later uptake by the tree root system.

Photograph 1. and Photograph 2. examples of TREENET inlet

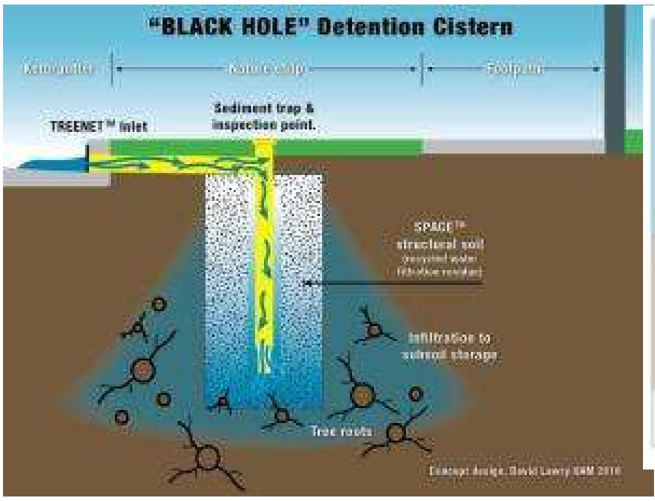


Figure 7. and Figure 8. TREENET Inlet Design

Water Sensitive Urban Design Development

Photograph 3. Vertical kerb lift resulting in ponding

Common street trees throughout Salisbury are E. leucoxylon (var.), E. torquata, and E. sideroxylon7. When planted within narrow verges and in close proximity to kerbing (within 600mm from back of kerb), the larger species of E. sideroxylon has presented lifted and broken sections of kerb. In turn ponding of stormwater after rain events is evident. Ponding within driveway crossovers and adjacent properties are regularly reported complaints to council, raising issues regarding standing water, build-up of leaf-litter and debris. As part of maintenance works, Councils Road Reseal and Kerb Replacement Programs aim to rectify lifted and damaged kerb, correcting the grade for storm water flows. Locations are identified by visual inspection following asset audits that rank streets according to road failures. In some cases to address ponding, twenty metres of kerb replacement is usually required to achieve appropriate grade. The average cost of replacing a standard section of kerb is $130 per lineal metre with council spending $700,000 in 2012/13 and with increased roads resealing in 2013/14 $1M for kerb replacement will be expected to be invested for the 2013/14. In many locations kerbing has been replaced numerous times to prevent such ponding. This ongoing work and repetitive replacement signified a change in thinking.

An investigation into alternate methods ensued. With the following points in mind six differing methods of implementing localised infiltration/ bio-filtration sumps ensued.

- Reducing ponded water within kerbing
- Improving soil moisture recharge
- Maximising contact surface area with the surrounding soil
- Varied methods of distributing captured water within the verge
- Depth of sumps relative to infrastructure and services
- Maximising volume capacity within sump
- Reduced spatial capacity for restricted verge spaces
- Reducing leaf litter and debris build up
- Minimise maintenance

Identified Risks

- Public safety included trip hazards, saturated/ boggy areas,
- Vandalism
- Vehicle damage
- Proximity to infrastructure
- Root damage during excavation

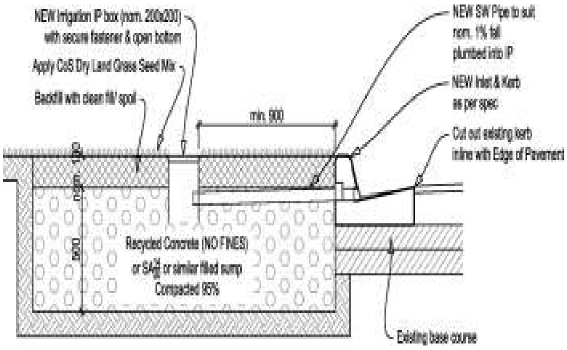
As a launching point Council required an initial test location for the six options; Orlyk Street Para Hills West was chosen as the test site. This street was selected due to the amount of locations presenting standing water within the kerb and the presence of mature street trees (E sideroxylon).

Initial installation of the infiltration sumps was undertaken by existing contractors for kerb and gutter replacement. Training was required for the contractor to understand the differing method of installing the TREENET Inlet and infiltration sumps. Continued implementation of these infiltration sumps relies upon effective monitoring and asset take-up by Council maintenance staff.

Sump Treatment	Dimensions (WxLxD)	Net Sump Volume (Pore Space cum)	Contact Surface Area (sqm)
ITD-01	1x1x1	0.6	4
ITD-02	1x2x1	1.2	6
ITD-03	2x2x1	2.4	10
ITD-04	1x1x1	0.6	5
ITD-05	0.7x3x0.4	0.504	3.86
ITD-06	2x2x0.5	0.2	8
ITD-10	1x1x1	0.6	5

Figure 9. Salisbury Council Infiltration Sump Designs

[7] Streetscape Planting Register, City of Salisbury



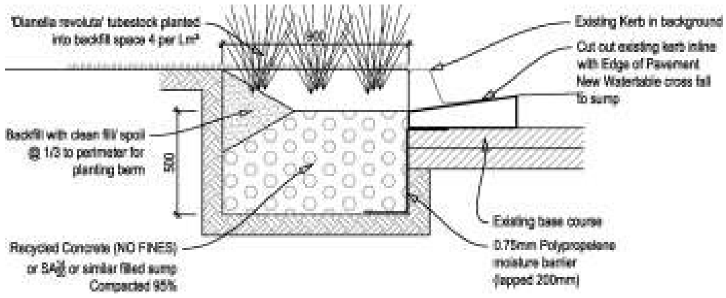
Photograph 4. and Figure 10. Salisbury Council behind the kerb design using the TREENET inlet faceplate

Leaf litter within kerbing is generally cleared from kerbing as part of Council's Verge Cutting Program. The program is programmed on a 5 – 8 week cycle of grass reduction (May to December) and accompanied removal of clippings from footpaths and driveways. Street sweeping follows within 48hours of cutting activities8 collecting leaf litter and debris from kerbing simultaneously. Autumn signifies the flowering of E sideroxylon and the migration of the Cacatua galerita (Sulphur Crested Cockatoo), Glossopsitta concinna (Musk Lorikeet) and Platycercus elegans (Crimson Rosella) to the district. Large numbers of these birds foraging amongst the street trees shed leaf litter and trimmed branch-lets onto the roadway. Consequently autumn rains flush this leaf litter along the kerb. Due to the overland storm water system upon flat grades, leaf litter and debris exacerbates localised ponding to occur within kerbing. During high intensity rain events side entry pits (SEP) can become choked with leaf litter and debris, slowing down the storm water flows. This causes the SEP to back up and local flooding ensues. Council has programmed vacuum clearing of SEPs to prevent blockages; it is unrealistic to rely on this program to offset the total volume of litter during certain times of year.

To counter the build-up of leaf litter and debris in front of the Tree Inlets face plates and SEPs leaf litter collection/ infiltration bays have been developed. Infiltration bays or Rain Gardens are anticipated to reduce roadway debris with select street tree species. The design of these relies upon gravity, as its precedent the slotted kerb and swale approach does. As storm water discharges along the kerb, it flows past the infiltration bays; the open kerb causes the storm water to fall into the Rain Garden carrying with it any leaf litter or debris. The Rain Garden is a trench of two meters long filled with 20mm aggregate screenings and the edges are battered with local spoil and planted with native grasses. Storm water discharges down through the profile of the Rain Garden, leaving leaf litter and debris upon the surface of the aggregate. Upon saturation of the infiltration bay and immediate surrounding soil, the Rain Garden at full capacity allows the storm water continue its path along the kerb; as it would had the infiltration bay not have been there. During high intensity flows, leaf litter and debris is anticipated to be continually deposited and removed to within the Rain Garden due to a naturally occurring eddy9.

8 Verge Cutting Program, City of Salisbury
http://www.salisbury.sa.gov.au/Our_City/Vehicles_Parking_Transport_and_Roads/Footpaths_and_Verges/Verge_Cutting_Prog ram

[9] *Eddy* (fluid dynamics): In fluid dynamics, an eddy is the swirling of a fluid and the reverse current created when the fluid flows past an obstacle. The moving fluid creates a space devoid of downstream-flowing fluid on the downstream side of the object. Fluid behind the obstacle flows into the void creating a swirl of fluid on each edge of the obstacle, followed by a short reverse flow of fluid behind the obstacle flowing upstream, toward the back of the obstacle.
http://en.wikipedia.org/wiki/Eddy_(fluid_dynamics) accessed 10/07/2013



Photograph 5. and Figure 11. Salisbury Council Water Sensitive Urban Design

The methods explored thus far include nine designs using the TREENET Inlet and two Rain Garden deisgns consisting of various sized unlined sumps filled with 20mm aggregate, with three different ways of dispersing the inflow around the sump. The variation in size has been designed to accommodate different storm water volumes, available space within verge area including the placement of sumps below footpaths and driveway crossovers; and maximise contact surface area with the surrounding soil.

Implementation of infiltration and bio-filtration sumps has required the cooperation of Council Tree Services staff identifying in-appropriately planted street trees for removal and replacement plantings adjacent TREENET Inlet sumps. This cooperative approach has expedited the process and timing of works. Using the TREENET Inlet sumps in proximity to replanting's has raised the opportunity to test the benefits of street tree establishment. Exploring further has led to Tree Services staff actively pursuing problematic trees for removal, replant and placement of TREENET Inlet. Previously where staff displayed apprehension in removing problematic trees due to re-establishment concerns; the TREENET Inlet has empowered staff to take positive steps towards replanting locations.

Trees and Infrastructure and the Heat Island Effect

Pavement stresses can be attributed to many factors and heat being one that can be reduced by shading using the trees canopy. Salisbury Council is currently using Micro surfacing treatments, polymer road stabilisation in conjunction with WSUD.

Randrup et al. (2003) suggested that certain pavement construction methods may even promote damage to pavements by tree roots. It was explained that soil moisture loss by evaporation can be blocked by the barrier such as a concrete or asphalt pathway. Due to the evaporation barrier affect, there are differences in temperature between the soil and pavement and this causes the soil moisture to condense on the underside of the pavement. Damage is caused therefore to the pavement surface by the root growth being attracted to this condensation moisture at the soil/concrete interface. Randrup et al. (2003) proposed that pavements constructed from porous materials that limit condensation and lower the temperature under concrete slabs may reduce the incidence of rooting at the interface and the subsequent damage this can cause.

The negative environmental impacts of treeless streets (this includes enhanced heat island effects) has been researched significantly, plus continued concern about the impacts of climate change have helped sway a change in attitude toward urban street trees by town planners and designers; (Shashua-Bara and Hoffman, 2000) - it is duly acknowledged that urban street trees provided positive economic and environmental benefits to the community10.

Salisbury recognises the important role that street trees play in urban environments has launched research into developing alternate methods of passively irrigating street trees that may lower maintenance costs and promote healthier and faster growing trees.

[10] *Trees as essential infrastructure: Engineering and design considerations.* pg19 par 5, Beecham S. School of Natural and Built Environments and Centre for Water Management and Reuse. University of South Australia

Opportunities for using Water Sensitive Urban Design

By implementing TREENET Inlets/rain gardens throughout the council area it is envisaged improvements in the community's amenities may, include but not limited to the following:

Mitigate Infrastructure damage by reducing kerb replacement works and pavement deterioration

- Minimise impact on established trees
- Improve establishment of street tree planting using water sensitive urban design
- Catchment of nitrates, particulates, pollutants and organics and improve soil moisture for street trees.
- Reduce first flush pulses
- Reduce silt build up in Council Wetlands
- Reduce storm water volumes discharging out to sea
- Reduced maintenance practices by redirecting leaf fall and diverting water prior to the CoS pipe network. Work Health and Safety improvement by lessening the requirement to clean side entry pits.
- Reduced impact of the heat island affect from heat pavement reflection.

Author Biographies

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Peter's early career was focussed on skatepark design and promotion of this form of recreation culminating in 2009 with a redevelopment masterplan for Canberra's Belconnen Skatepark to become Australia's largest.

During University of Adelaide studies in landscape architecture he worked with Taylor Cullity Lithean and credits a rigorous design ethos with this experience.

Since 2008 Peter has been employed at City of Salisbury working on a range of landscape and biodiversity projects.

Peter is a strong advocate for water sensitive urban design in local government.

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Peter Levett

Capital Works Officer, City of Salisbury SA

Peter Levett is a highly experienced practitioner in civil and landscape construction and maintenance in local government public works with major metropolitan Adelaide councils.

In his current role at City of Salisbury Peter administers a significant road surfacing program and other civil works. He has lead initiatives to achieve carbon reduction strategies and is active in cross council forums seeking improved industry standards in road surfacing.

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(1) Trees as essential infrastructure: Engineering and design considerations. Beecham S. School of Natural and Built Environments and Centre for Water Management and Reuse. University of South Australia

(2) Plant available moisture in stone-soil media for use under pavement while allowing urban tree root growth. Grabosky J, Haffner E and Bassuk N in Arboriculture & Urban Forestry, 35(5), 271-278. (2009)

(3) A review of tree root conflicts with sidewalks, curbs and roads. Randrup T B, McPherson E G and Costello L R in Urban Ecosystems, 5, 209-225 (2001).

(4) Vegetation as a climatic component in the design of an urban street: An empirical model for predicting the cooling effect of urban green areas with trees. Shashua-Bara L and Hoffman M E, in Energy and Buildings, 31(3), 221-235 (2000)

(5) From The Gutter To The Stomata By The Closest “Root” David Lawry

(6) The benefits of Adelaide’s street trees revisited Professor Randy Stringer

(7) Are street trees and their soils an effective stormwater treatment measure? Liz Denman

(8) Salisbury Development Plan

(9) Sustainable Futures

- The Prosperous City 1.2 Support the development of a workforce possessing the skills required to adapt to industry restructuring and meet the needs of growth orientated industry sectors.
- The Prosperous City 2.2 Deliver high quality urban development incorporating sustainability, connectivity, diversity and integrated urban design principles.
- The Prosperous City 3.5 Build on Council’s investment in water reuse projects to attract investment, contribute to urban amenity and support local firms.
- The Sustainable City 4.1 Further maximise re-use opportunities and mitigate the impacts of storm water inundation and flooding.
- The Sustainable City 5.2 Ensure that existing and future urban environments are able to withstand and adopt to future demands.
- Achieving Excellence 6.3 Use expertise, knowledge and technology to improve and develop alternative modes of service delivery.

URBAN FOREST – HELPING TO AMELIORATE THE EFFECTS OF POLLUTANTS ENTERING COASTAL HABITAT

Professor Sean Connell
University of Adelaide

For further reading about Sean Connell's subject matter refer to the following publications:

Connell SD (2007) Water quality and the loss of coral reefs and kelp forests: alternative states and the influence of fishing. In: Connell SD, Gillanders BM (eds) Marine Ecology. Oxford University Press, Melbourne https://www.researchgate.net/publication/236844345_Connell_SD_2007_Water_quality_and_the_loss_of_coral_reefs_and_kelp_forests_alternative_states_and_the_influence_of_fishing_In_Connell_SD_Gillanders_BM_eds_Marine_Ecology_Oxford_University_Press_Melbou

Gorman D, Russell BD, Connell SD (2009) Land-to-sea connectivity: linking human-derived terrestrial subsidies to subtidal habitat change on open rocky coasts. Ecol Appl 19:1114-1126 https://www.ncbi.nlm.nih.gov/pubmed/19688920

Falkenberg LJ, Connell SD, Russell BD (2013) Disrupting the effects of synergies between stressors: improved water quality dampens the effects of future CO2 on a marine habitat. Journal of Applied Ecology 50:51-58 http://onlinelibrary.wiley.com/doi/10.1111/1365-2664.12019/full

European Commission's Environment Directorate-General highlighted the last paper as providing a unique insight into the vital scientific issues relevant to current EU environmental policy

TREE ESTABLISHMENT IN THE URBAN ENVIRONMENT.

Michael Leers
University of Melbourne

Introduction

The urban environment may be considered one of the harshest planting and growing environments (Appleyard, 2000, Craul, 1993, Gilman, 1993, Simpson, 1981). The London Tree Officers Association expected a 50% tree replacement rate within their municipality as a result of failed establishment or from damage/vandalism (Appleyard, 2000). Therefore, it is not surprising or uncommon to see newly planted street trees either dead or dying. A number of factors are likely to be responsible and may include any one, or a combination of, poor quality or inappropriate planting stock, inadequate planting techniques or inadequate maintenance (Appleyard, 2000, Gilman, 1993, Leers, 2000, Messenger, 1976, Moore, 1997b, Watson, 1997, Watson and Kupkowski, 1991). It is also clear that the availability of growth resources play a critical role in a tree's development. Development can also be modified by the environment (Salisbury and Ross, 1992, Shigo, 2008). Recommendations such as correct planting depth, effective irrigation and other maintenance regimes responsible for successful tree establishment have been set (Gilman, 1993, Leers, 2000, Moore, 1997a, Smith, 1997, Watson, 1997).

A number of authors believe that the soil condition should be the primary consideration when evaluating urban sites for tree planting (Craul, 1993, Cutler et al., 1990, Smith, 1997). However, the microclimate of an urban planting site also needs to be considered when planting trees because of its effect on photosynthesis and growth (Kjelgren and Clark, 1992). For example, trees growing in areas of extensive paving will experience a higher Vapour Pressure Deficit and require greater evaporative cooling than trees in unpaved areas or "vegetated" areas, in turn requiring greater scrutiny with species selection (Bassuk and Whitlow, 1985, Irfan et al., 2001, Kjelgren and Clark, 1992, Rosheidat and Bryan, 2010).

Kjelgren and Clark (1992) found that urban microclimates affect and influence tree growth and physiological responses. In urban settings with paving and buildings, they found tree growth acclimated physiologically and developmentally to the conditions with decreased trunk growth or canopies being sparse and stunted, compared to other trees in more park-like settings. Urban microclimates and the urban heat island effect are proving to have an increasingly negative effect on plant growth (Bassuk and Whitlow, 1985, Irfan et al., 2001, Kjelgren and Clark, 1992, Rennenberg et al., 2006, Rosheidat and Bryan, 2010, Schiavo, 1991). As a result tolerance of high temperatures and or rapid temperature fluctuations may well become a primary consideration for tree selection in many urban environments (Costello et al., 2003, Litzow and Pellett, 1983, Rennenberg et al., 2006, Roppolo and Miller, 2001, Shirazi and Vogel, 2007)

High temperature injury (HTI) is caused by extreme or critically high temperatures (Costello et al., 2003, Larcher, 1995, Levitt, 1956, Pichler and Oberhuber, 2007, Rennenberg et al., 2006, Rosheidat and Bryan, 2010, etc). The HTI threshold temperature range as 44°C to 50°C for evergreen conifers during the growing season (Larcher 2003 in Pichler and Oberhuber, 2007 p. 696). Similarly, Levitt (1956) refers to the accepted range of 45°C to 55°C as the limit for most plants. While Kozlowski (1979) believes direct HTI occurs in the 45°C to 60°C range. The knowledge that trees can survive 60°C as compared to 50°C will be important when selecting appropriate species for some urban environments. Aside from the extreme temperatures, Kozlowski (1979) states that temperatures a little lower than those cited usually cause indirect injuries. He also believes that typical HTI damage (sunscald, bark scorch and desiccation) is accentuated by large fluctuations in diurnal temperatures. It is well known that plant temperatures can rise above the ambient temperature, up to 10°C in some plant organs, so ambient temperatures do not directly relate to HTI of plants (Levitt, 1956). He cites examples of soil temperatures 14°C greater than the air temperature and cambial tissues of Spruce trees being 18°C higher than the air temperature. Though it is clear high temperatures cause damage to plant parts, the exact injury threshold temperatures cannot be determined for trees growing in the urban environment due to the effects of other micro-climate variables. Because of the increased rates of transpiration, high temperatures can cause desiccation leading to reduced growth rates and eventually death (Kozlowski, 1979).

Performance of photosynthesis is strongly connected to nutrient uptake and partitioning and competition for nutrients. Further, high temperatures stimulate photorespiration at the same time as inhibiting photosynthesis and carbon metabolism is strongly connected to stress (heat and drought) compensation mechanisms (Fitter and Hay, 2002, Larcher, 1995, McDowell et al., 2008, Rennenberg et al., 2006, Salisbury and Ross, 1992). Europe's heat wave in 2003 led to decreased photosynthesis production in Mediterranean forests and ecosystems (Garcia-Plazaola et al., 2008, Rennenberg et al., 2006). It is clear that heat and drought (though with distinctive effects) are responsible for this reduction. However, the metabolic processes affected that contribute to this reduction are not always apparent. Garcia-Plazaola et al (2008) and Rennenberg et al (2006) discuss a number of processes that may decrease carbohydrate synthesis. Rennenberg et al (2006) hypothesize that rapidly increasing high temperatures and sustained moderate increases in temperature affect the photosynthetic system differently. Heat tolerance of plants may be increased by exposure to sub-lethal high temperatures as the plant synthesizes heat shock proteins, isoprene and antioxidants in order to protect the photosynthetic apparatus (Kozlowski and Pallardy, 2002).

During exposure to surface fires, Dickinson and Johnson (2004) discuss the temperature threshold for vascular cambium tissue mortality as 60ºC during simulations. However, they go on to cite this threshold not being applicable to other tissues. Biological factors such as species, bark thickness and stem diameter significantly affect heat resistance (Dickinson, 2004, Mantgem, 2003) Importantly, tree stem cell and tissue impairment is dependent on the rate of temperature increase and duration of exposure (Dickinson, 2004, Jones et al., 2006). Dickinson (2002) discusses the problem with citing threshold temperatures is that cell necrosis occurs at lower temperatures with increased exposure. He describes that cambium tissues are damaged at about 43°C.

Sunburn is defined as injury or death of plant tissues as a result of exposure to critically high temperatures from solar radiation (Costello et al., 2003). The discussion and evidence of the symptoms of sunscald, sunscorch and sunburn on the trunks of trees is clear (Bernatzky, 1978, Costello et al., 2003, Kozlowski, 1979, Kozlowski et al., 1991, Leers, 2000, Levitt, 1956, Roppolo and Miller, 2001, Rushforth, 1987, etc). In this paper, summer sunscald will be the term used to describe HTI to the trunks of tees in the warmer months. Trees that have developed in a closed stand undergoing heavy thinning and then exposed are highly susceptible to summer sunscald (Hermann and Lavender, n.d.). Summer sunscald on individual trees occurring in heavily thinned forest stands of trees may not be apparent for several years (Curtis et al., 2000, Kozlowski et al., 1991). This may be similar to a tree coming from a relatively sheltered nursery, then being transplanted into an exposed street. Also, there is anecdotal evidence of the canopies of trees growing at a particular orientation then transplanted facing another compass point exhibiting different growth rates (Moore 1998). That is, one side of the tree starts its life facing south, with very little conditioning against solar radiation, then is transplanted with that same side facing northwest where the bark experiences the shock of full sun intensity.

Figure 1. Symptom of mild summer sunscald on Melia azedarach Broadmeadows Vic noted in summer 2007/08

Plant moisture stress is a major factor increasing the potential for sunburn (Costello et al., 2003), but it can still occur on sensitive plants when adequate soil moisture is present (Costello et al., 2003). Not only moisture stress, but declining vigour and the tree canopy shape (vase shaped trees with big scaffold limbs) also affect the occurrence of summer sunscald (Litzow and Pellett, 1983). There is evidence that the pruning technique lion-tailing not only reduces photosynthetic ability, but also increase the potential for summer sunscald on thin barked trees (Smiley and Kane, 2006). Lion-tailing is the removal of all the smaller branches from the inside portion of a bigger branch, leaving the only foliage at the very tip of the branch. Another pruning practice, topping, where the ends of branches are removed, is also responsible for summer sunscald due to the sudden exposure of previously shaded bark (Trask, 1933).

Costello et al (2003) define sunburn as exposure to critically high temperatures from solar radiation leading to the dehydration and death of plant tissues. They state sunburn injury is linked to high ambient temperatures and is injury to the above ground parts of the plant, leaves flowers, fruit and bark. Of particular interest is damage to trunk and bark tissues. Mild summer sunscald, or the initial stages of summer sunscald of the trunk, appears as a reddish discolouration (Figure 1). As it progresses the bark shrinks, appears sunken then splits, exposing the sapwood (Figure 2 and 3) (Costello et al., 2003). Crane et al (1994) describe drying and peeling of the bark, branch dieback, wood injury and saprophytic fungi on dead bark and wood as a result of sudden exposure to direct sunlight for a prolonged period. They believe it is the over-heating of the cambium that causes these symptoms.

Figure 2. Symptom of severe summer sunscald on *Jacaranda mimosifolia*, Fremantle, WA April 2010

Figure 3. Symptom of summer sunscald on *Agathis robusta* growing in Rundle Park, Adelaide SA, September 2007

Bernatzky (1978), Kozlowski et al (1991) and Levitt (1956) also discuss the damaging effects of summertime HTI. The temperatures involved are usually below the thermal death point, with symptoms of scorched leaves and fruits, sunburn, leaf abscission and inhibited growth and scorched bark. Novis et al (2005) cite trees becoming unstable due to the death of the cambium, as a result of sunburn. Similarly, the USDA Silvicultural Handbook (1999) notes the necrosis of overheated cambial tissues as a result of sunburn in the warmer months. This in turn causes flattened sides, "bark sloughing" and poor wood quality. The Handbook discusses sudden exposure due to thinning and topping of tolerant species during the warm season causing sunburn. Biagorria and Romero (2010), also discuss tolerant species being susceptible to extreme levels of solar radiation causing sunburn, or summer sunscald. So it can be said summer sunscald is the result of relatively high ambient temperatures that tend to be localised, irrespective of latitude. Observations of the symptoms of summer sunscald on the western side of the trunk of transplanted trees in the urban environment may now be attributed to the sudden and extreme high temperature events experienced during the summer months.

An example of summer sunscald on the smooth barked *Acer truncatum* x *platanoides* 'Pacific Sunset' and *Acer truncatum* x *platanoides* 'Norwegian Sunset' in metropolitan Melbourne was identified in 2010. Some 27 of these trees were planted as street trees in an east to west layout over a period of one to six years before the summer sunscald symptoms were reported. Eleven trees had badly damaged bark or dieback of the cambium, all on the west facing side of the trunk (Figure 4 and 5) (Moore, 2010 pers.comm.).

Figure 4. Symptom of severe summer sunscald on *Acer truncatum x platanoides*, Melbourne, Vic 2010

Figure 5. Symptom of severe summer sunscald on *Acer truncatum x platanoides*, Melbourne, Vic 2010

A series of experiments were designed to investigate the causes of sunburn on the trunks of newly planted trees. These investigations also considered the effects of altered orientation when nursery grown trees are planted into the landscape. The experiments were conducted beginning in mid 2006 and ending in 2009 and evaluated the changes in the tree's growing conditions as a result of;

- altering the orientation of a tree when planted into the streetscape, so that it differs from that when grown in the nursery,
- the incidence of summer sunscald by testing the hypotheses that the greater the symptoms of summer sunscald the less the shoot tip extension,
- the effects of heat re-radiated from different surfaces by;
    - testing the hypotheses that the presence of a surface treatment (asphalt, concrete, granitic sand or mulch) on the western side of a newly planted tree will affect the temperature of the trunk of that tree and the growth of that tree (measured as shoot tip extension) in the first summer season after planting.
    - testing the hypotheses that heat radiated from a surface (asphalt, concrete, granitic sand or mulch) may induce trunk summer sunscald or worsen the extent of summer sunscald,

Each tree was measured for annual growth, in some cases for up to three consecutive growth years. The measurements used to evaluate growth were increases in tree trunk caliper and shoot tip extension (shoot growth). Measuring annual shoot tip extension, the distance between the scale scars and the terminal bud, is a suitable method of quantifying a plant's top growth (Watson, 1987, Watson et al., 1992). Increase in tree trunk caliper and increase in tree height are also considered to be appropriate and suitable measurements of tree growth (Gilman and Grabosky, 2004, Pichler and Oberhuber, 2007). To calculate the annual shoot tip extension, a ruler was used to measure the distance between the scale scar and the terminal bud, see Figure 6. Calculation of trunk caliper increase was determined by measuring the trunk caliper 100mm above soil level, measuring at the same point a year later and then determining the difference.

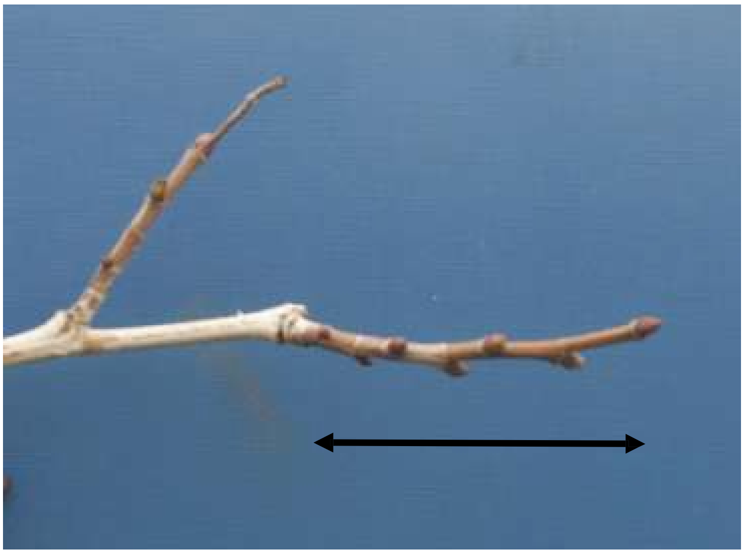

Figure 6. Indicating shoot tip extension from scale scar to terminal bud on Platanus x acerifolia.

Changed tree orientation

A total of 134 trees from 3 different species - *Platanus* x *acerifolia*, *Melia azedarach and Acer campestre* were used in this experiment. Before leaving the nursery, the trees were marked with a small spot of paint indicating the north facing side on the tree. The trees were then planted into three different streetscapes of Hume City Council, northwest metropolitan Melbourne. At the time of planting into the streetscape, this paint mark was positioned so that the trees were planted with a previously selected north, east, west or south compass point orientation so that a fully randomised design was created

Results showed no effect on shoot tip extension when altering tree orientation at time of planting, so that it is different from that when grown in the nursery. The literature review undertaken for this research did not find any support the hypothesis that tree canopies favour growing towards any particular compass point. The incidence and effects of summer sunscald will be discussed later, see Table 2.

Heat radiated from a surface may induce trunk summer sunscald

The experiment used 30 field grown, 45 litre rootball, Platanus x acerifolia that were planted along the centre median of Pascoe Vale Road, Broadmeadows in the winter of 2007. Directly adjacent to each tree on the west side, a 0.5m2 surface was installed in a timber plinth box, with a 50mm space between the tree and plinth. The four surfaces used were asphalt, concrete, granitic sand (decomposed granite, commonly used as a pavement treatment in Melbourne) and organic mulch. All are commonly found surrounding or adjacent to urban trees. Tree orientation at planting was changed, as with the previous experiment, by marking the north facing side of the tree. Half the trees were planted with their original north facing

orientation facing north and half had their original orientation turned to face south. Therefore, the experiment was set up having 30 trees in total with 14 facing north and 16 facing south. The trees planted alongside asphalt and granitic sand had four replicates for each orientation. The trees planted alongside concrete and mulch each had three trees facing north and four trees facing south. This created a Fully Randomised Design.

Surface temperatures of the tree trunks and of the adjacent surfaces were recorded using thermal imaging (Figure 7). The thermal imaging was conducted in early March 2008 using a 7710 model, NEC® Thermal Image Camera. A Thermographic Report presented conventional photographs alongside thermal images of each individual tree. Information provided was the location, the tree identification number and the surface, the date and time the photographs were taken and the ambient temperature at the time each photo was taken. A total of three thermal images and photographs were taken for each tree on 3 March 2008, comprising an image and photograph taken in the morning from 6.48am to 7.28am, afternoon from 2.33pm to 3.04pm and late afternoon from 7.26pm to 7.48pm.

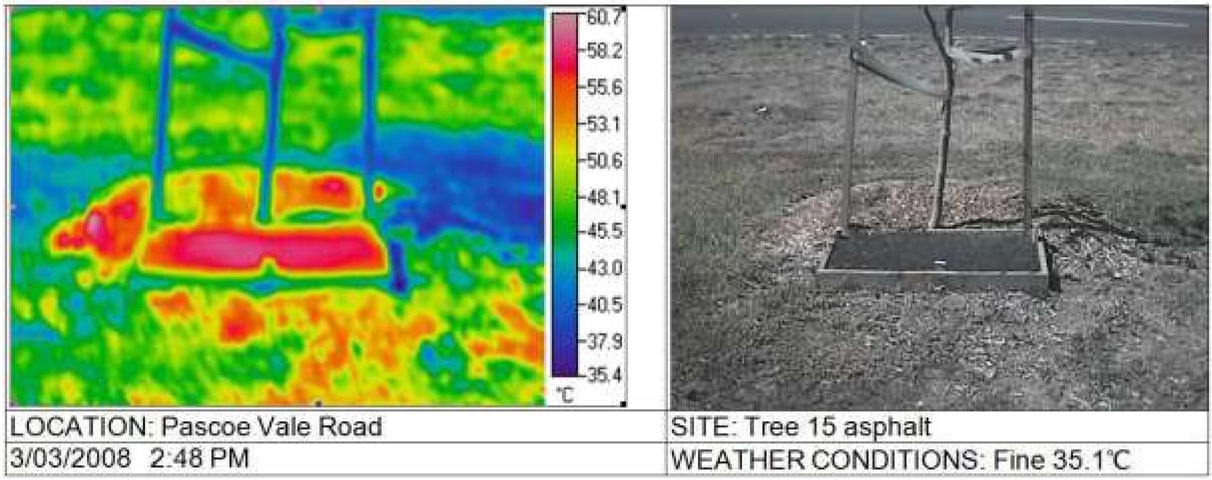

Figure 7. A thermal image photograph alongside a conventional photograph of Tree 15 taken at 2.48pm.

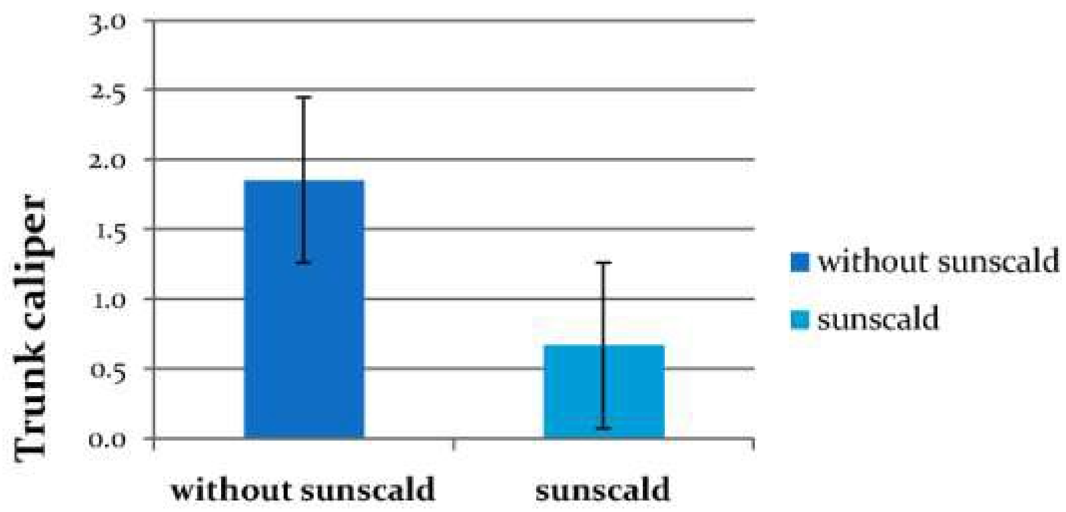

Figure 8 Trunk caliper increase for *Platanus* x *acerifolia* with and without sunscald

Results showed no significant treatment effect of treatment surface or tree orientation on shoot tip extension. Though, a Two Sample T- test showed a significant treatment effect, with greater caliper increase for those trees without summer sunscald, Figure 8.

Table 1 compares the mean temperatures for each surface at time of measurement. Means are separated using 95% confidence intervals. Standard deviations are shown in brackets. For each time period, means with the same letter beside them are not different ($p < 0.05$). These results clearly indicate that by the afternoon, concrete and asphalt are hotter than granitic sand and mulch. This implies that they will also radiate greater heat than the other surfaces.

Surface treatment	Morning mean temperature	Afternoon mean temperature	Late-afternoon mean
Asphalt	14.3°C (0.5)ab	53.5°C (1.3)a	28°C (0.6)a
Concrete	13.1°C (0.7)b	39.57°C (1.4)c	27.7°C (1.1)a
Granitic sand	12.6°C (0.7)b	44.5°C (1.9)b	23.9°C (1.6)b
Mulch	14.9°C (0.9)a	53°C (1.5)a	23.4°C (1)b

Table 1. Mean temperatures for each treatment surface at time of measurement.

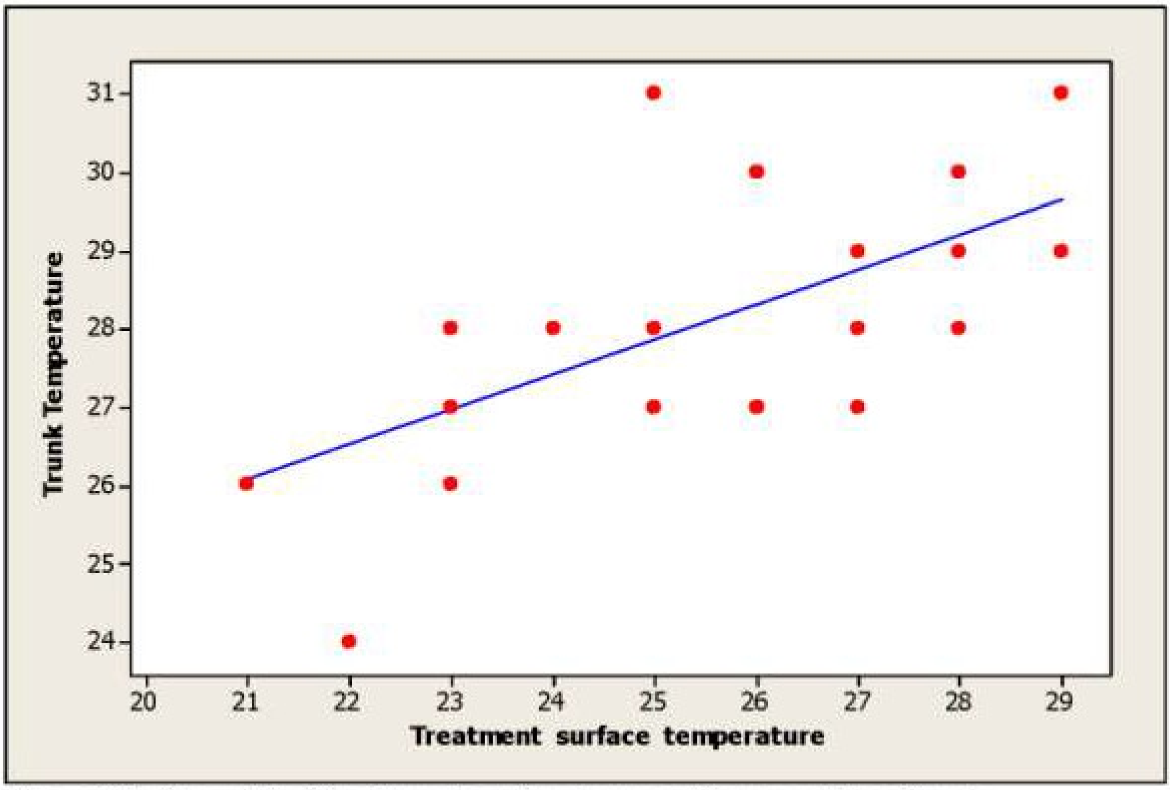

Figure 9 Scatterplot of treatment surface temperatures and tree trunk temperatures (°C) r2 = 46.9%

Scatterplots with regression lines were prepared to evaluate any relationship between treatment surface temperatures and tree trunk temperatures at the three measurement times. No correlation was present at the morning and afternoon measurements. However, a low positive correlation was present in the late afternoon (r^2 = 46.9%), Figure 9. When considering Figure 9 alongside the data presented in Table 1 and Figure 8, planting trees alongside paved areas requires consideration of the possible effects of radiated heat.

In order to provide further background about the growing conditions experienced during all of the experiments, Bureau of Meteorology climate data recorded at the Melbourne Airport station and taken from the Bureaus website is presented and discussed.

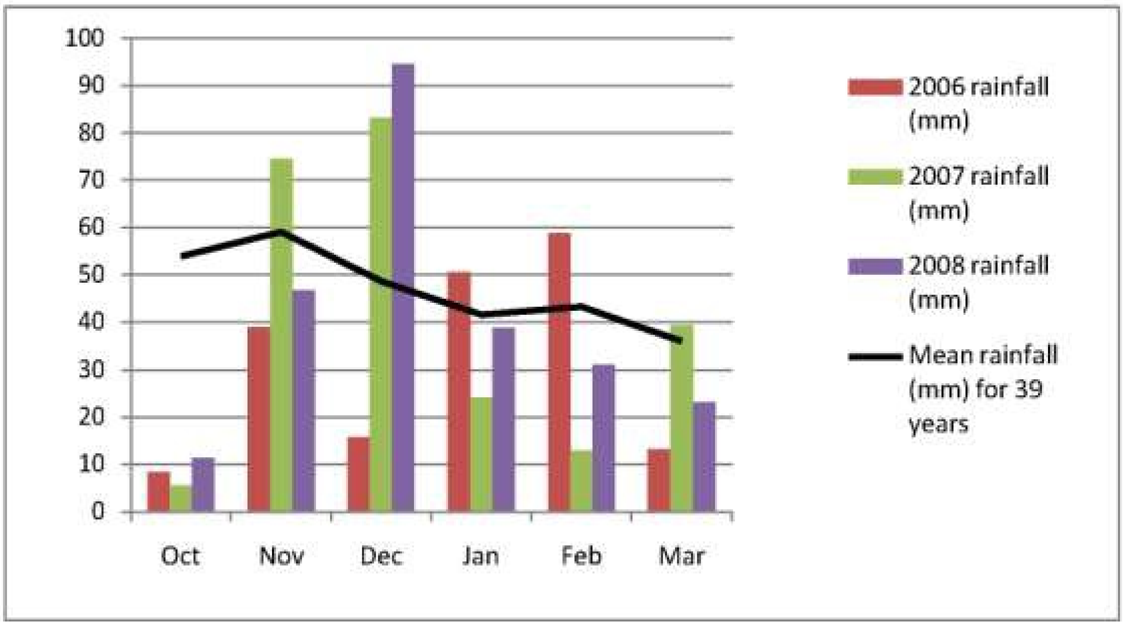

Figure 10 The 39 year mean rainfall over total monthly rainfall during the growing seasons for the years 2006 to 2008.

Figure 10 shows monthly rainfall in millimetres during the growing seasons from 2006 to 2009. These were the years data were collected from the two in-ground experiments; the Changed Tree Orientation Experiment and the Effect of Paving Surfaces on Newly Planted Trees Experiment. The graph indicates six months out of a total of eighteen growing season months received above average rainfall. The remaining thirteen "growth" months received well below average rainfall. This coincides with the well reported ten year dry period that was experienced in Victoria from the late 1990's to 2010.

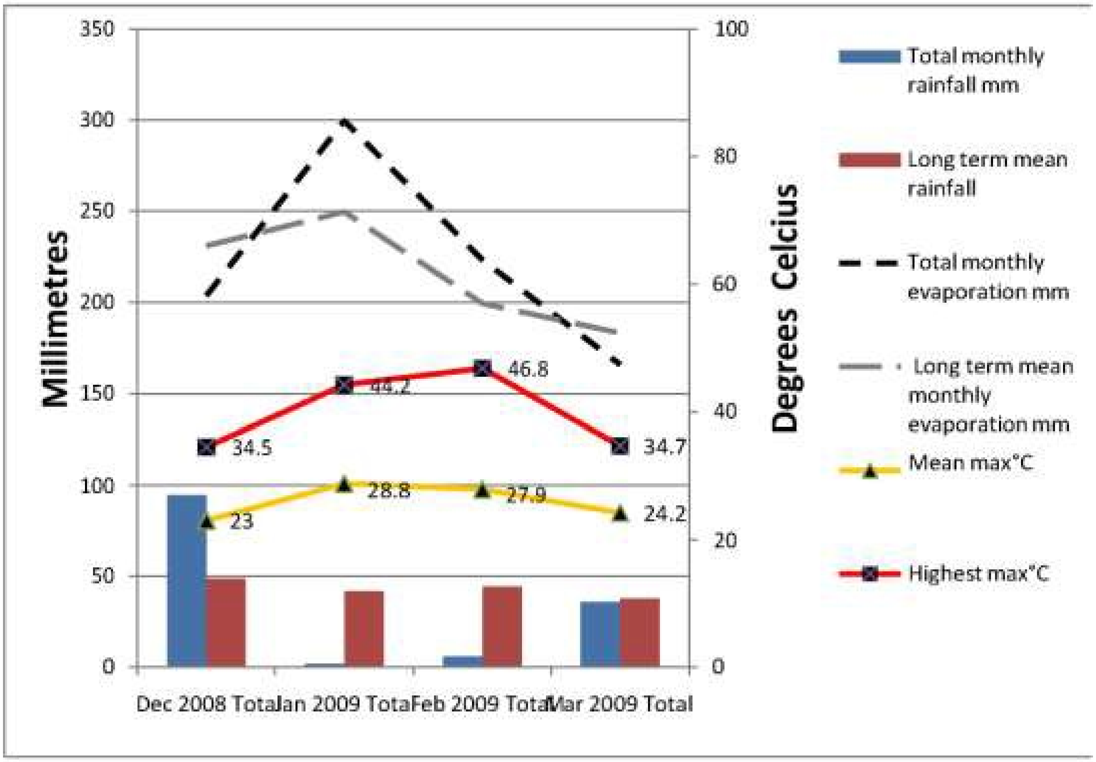

Figure 11 Total monthly and mean monthly evaporation over total monthly and mean monthly rainfall and highest monthly and mean maximum monthly temperatures for December 2008 to March 2009.

Figure 11 shows climatic conditions from December 2008 through to March 2009. Shown are the total monthly temperature and rainfall figures alongside their long term averages, over these figures is total evaporation and long term average evaporation for each month. Though the month of December 2008 received above average rainfall, 26 days received less than 2mm, with two successive days each receiving above 40mm rainfall. Other than the two above average rainfall events, much of 2008/09 growing season experienced well below average rainfall and above average temperatures with high rates of evaporation, with January and February experiencing a peak in total evaporation, well above the 10 year average, taken from 1999 to 2009. This trend certainly contributed to the extreme and devastating events in Victoria on 7 February 2009, known as Black Saturday where very high temperatures resulted in devastating bushfires.

Table 2 details the total numbers of trees in each experiment alongside total numbers of deaths, observations of summer sunscald and numbers of trees receiving various forms of intentional or accidental

vandalism (such as mower damage). The table indicates some street plantings received a little more than 10% vandalism while others received none. This is not atypical of tree plantings in the urban environment. Also evident are the high numbers of tree deaths for *Platanus* x *acerifolia* compared to *Acer campestre* and *Melia azedarach*. Despite this death rate, only 10% of studied trees showed summer sunscald, while 30% of the nursery grown trees received some level of summer sunscald.

	Alive	Dead	Sunscald	Vandalism
30 x *Acer campestre* 2008	30	0	0	4
46 x *Melia azedarach* 2007	46	0	3	0
46 x *Melia azedarach* 2008	46	0	0	4
58 x *Platanus* x *acerifolia* (Changed Orientation) 2007	33	25	3	1
33 x *Platanus* x *acerifolia* (Changed Orientation) 2008	29	4	3	1
30 x *Platanus* x *acerifolia* (Effects of Paving) 2008	18	12	3	0

Table 2. Total numbers of trees in each experiment alongside total numbers of deaths, trees displaying summer sunscald and trees vandalised.

As could be expected, the climate provided difficult growing conditions, having a negative impact on the growth of all trees used in the two in-ground experiments (Costello et al., 2005, Gilman, 1993, Hitchmough, 1994, Leers, 2000, Moore, 1997b, Watson, 1997). Considering the below average rainfalls alongside the observed data from all the experiments and the death of almost 50% of trees from the experiments, the measured growth responses may be attributed to these extreme conditions (Allen et al., 2010, Larcher, 1995, McDowell et al., 2008, Street and Öpik, 1984)

Even under the conditions of the experiments, particularly the below average rainfalls and high temperature and evaporation rates experienced during the growing season, the intensity and duration of conditions required to induce summer sunscald were not in evidence to the degree that has been observed elsewhere. However the results from the experiments and associated review have shown that transplanting a nursery grown tree, so that its original trunk and canopy orientation is changed, does not affect tree growth. They have also shown that the surfaces of asphalt and concrete are hotter than mulch and/or granitic sand and as such can re-radiate more heat than mulch and/or granitic sand.

The results from the experiments and associated review have not proved that heat re-radiated from paving surfaces negatively affects the growth of newly planted trees. Further they have not proved that heat re-radiated from different paving surfaces induces summer sunscald on newly planted trees. Finally, that tree growth is adversely affected the greater the symptom of summer sunscald has not been proved. Because these hypotheses have not been clearly answered, it is hoped this document will form the basis for further research into the causes and effects of summer sunscald.

Applying these lessons

Perth conditions

The climate of the Perth region is typical Mediterranean with dry, hot summers (mean monthly maximum greater than 30° C) and wet, mild winters (mean monthly minimum greater than 8° C). The average annual rainfall at Perth Airport is 773mm, in Perth's northern regions average rainfall is 606mm and for the western regions, 721mm while the base of the escarpment can get average rainfall around 820mm. The summers are dry with more than 80% of the annual average rainfall occurring between May and October. The south-west of Western Australia has experienced noticeable changes in climate, with a general trend of declining annual rainfall since the mid 1970's, Figure 12. Climate change predictions for the Perth region are increased mean temperatures and lower rainfall. Further, these declines in winter rainfall will result in a significant decrease in stream flow and groundwater recharge (Wilson and Valentine, 2009).

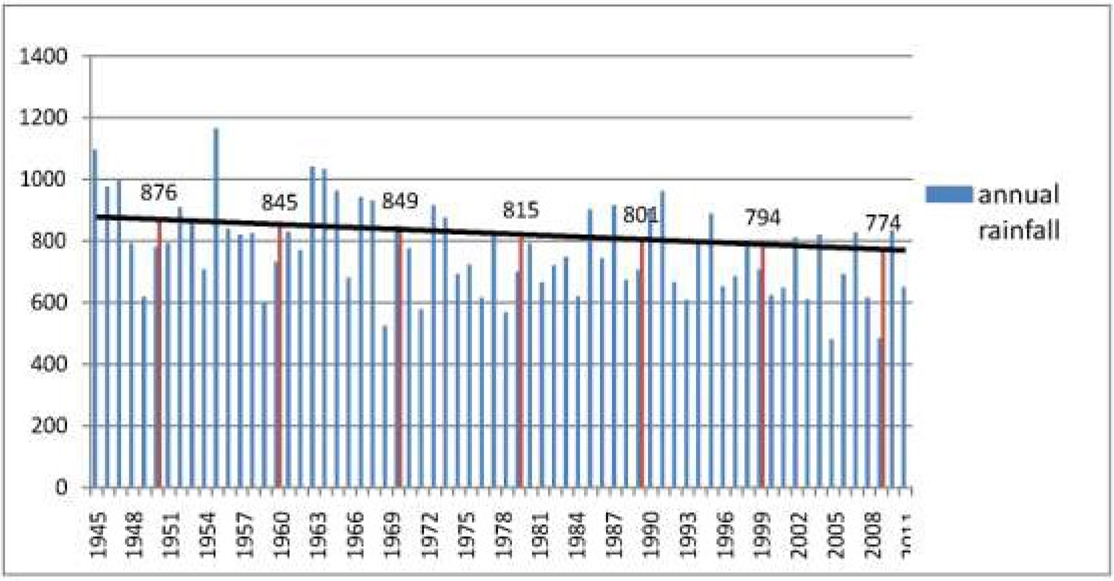

Figure 12 Perth airport total annual rainfall, 1945 to 2011

Climate modelling by CSIRO shows that average annual rainfalls are projected to decline in the south-west of Western Australia by as much as 20% by 2030 and 60% by 2070. In the last 35 years, reduced rainfalls have resulted in decreased flow to public water supply dams by more than 50% on average and decreased recharge to aquifers has also occurred due to climate variability. Groundwater falls of the Gnangara Mound of up to 4 m were recorded over the period 1979–2004 Figure 13. Significant rainfall declines combined with increased supply for public and commercial water needs as well as increased evapotranspiration are the contributors to this outcome.

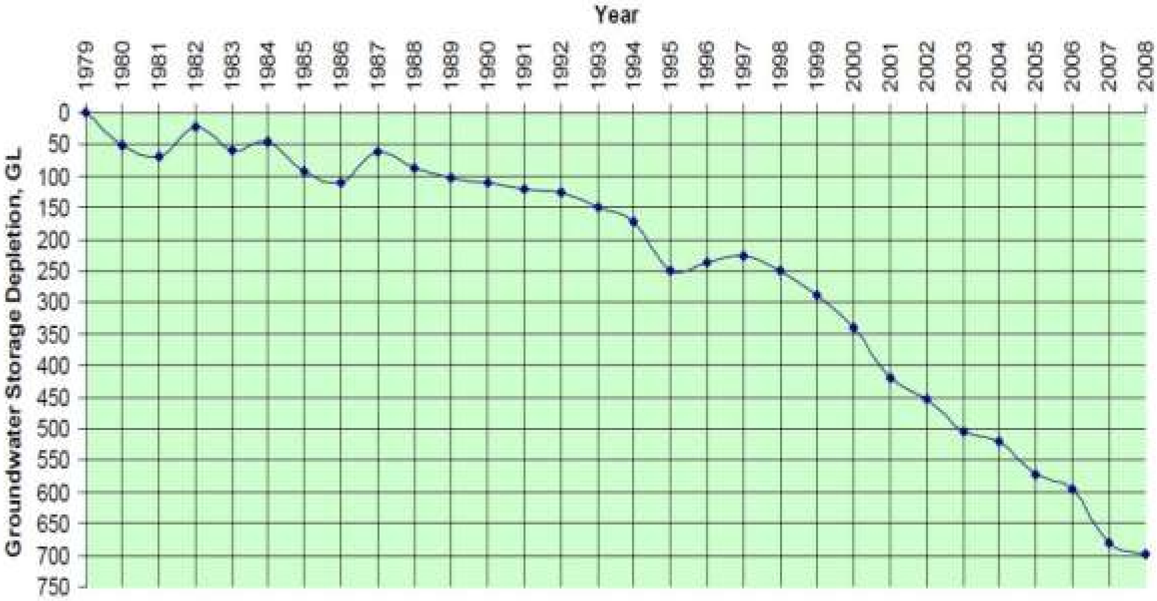

Figure 13. Groundwater depletion relative to 1979 level

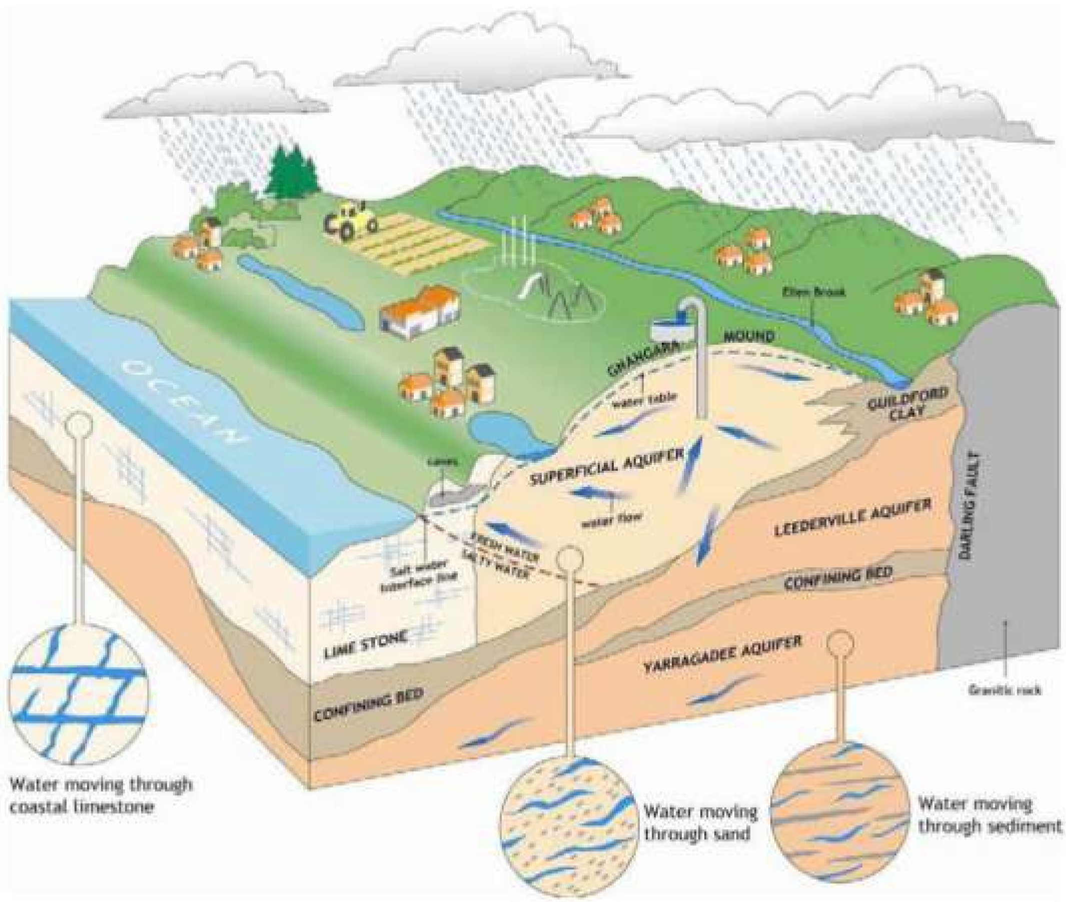

Figure 14 Gnangara groundwater system hydro-geological cross-section

Gnangara groundwater system incorporates a number of aquifers, including the Gnangara Mound or superficial aquifer, which is a shallow unconfined aquifer, the semi-confined Mirrabooka aquifer and theLeederville and

Yarragadee aquifers that are deep and more confined aquifers that extend north and south beyond the extent of the Gnangara Mound, Figure 14.

Drought related tree mortality

Moisture stress can affect plant growth, from short term impacts on cells and their processes to longer term impacts on root and shoot growth and even death. It is the disruptions to the photosynthetic apparatus and carbon metabolism that will have the greatest negative impact on the establishment of a newly planted street tree due to the reduction in shoot and root growth, amplified by the internal redirection of allocated resources away from the finer roots (Apostol et al., 2009, McDowell et al., 2008, Pichler and Oberhuber, 2007, Watson, 1997, Werner et al., 2001). Even though some of these drought induced effects are reversed as water again becomes freely available (Fitter and Hay, 2002, Larcher, 1995, Salisbury and Ross, 1992), the establishment of the new street tree is delayed or stopped by drought periods or those extended periods of moderate to severe moisture stress (Gilman, 1997, Smith, 1997, Watson, 1997, Whitcomb, 1987).

McDowell et al (2008) discuss three contributing factors of drought related tree mortality which are consistent with other theoretical and empirical results (Figure 15). Hydraulic failure occurs due to reduced soil water availability and then coupled with high evaporative demand causes xylem cavitation. This stops water flow through the tree and leads to desiccation of tissues and when duration and/or intensity of moisture stress is severe enough, the whole plant desiccates. McDowell et al (2008) mention anecdotal observations of mature tree mortality in the absence of pathogens. However, it is not clear if hydraulic failure alone was the cause. Carbon metabolism is disrupted with stomatal closure and the uptake of carbon diminishes and the tree starves because metabolic demand is still current. This may be exacerbated by photoinhibition or increased respiration associated with increased temperatures typical in drought periods. McDowell et al (2008) cite evidence of the link between tree death and carbon availability – trees dying with decreased stem wood growth rates and increased growth variability, though this may be species related. Finally, environmental drought conditions drive changes in the demographics of plant pathogens (insects, fungi, bacteria). The growth rates, population size and/or mortality of some pathogens will be favoured by these conditions, though the exact dynamics for all species are not yet known. These changes may occur in conjunction with the tree's physiological responses and condition (McDowell et al 2008).

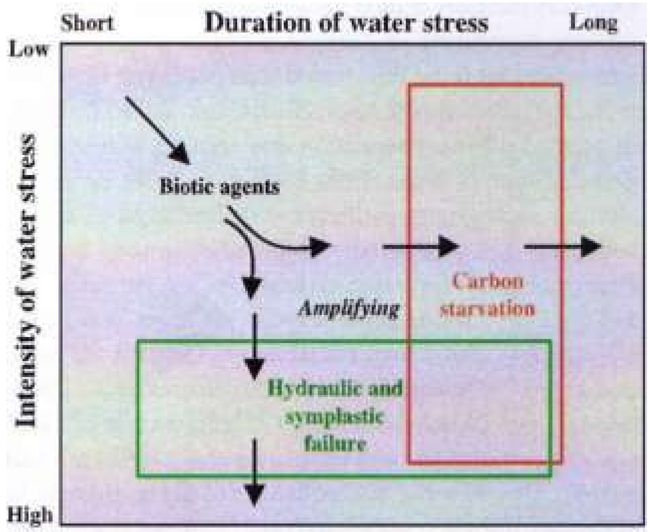

Figure 15 Theoretical relationship, based on the hydraulic framework between the temporal length of drought (duration), the relative decrease in water availability (intensity), and the three hypothesized mechanisms underlying mortality. Carbon starvation is hypothesized to occur when drought duration is long enough to curtail photosynthesis longer than the equivalent storage of carbon reserves for maintenance of metabolism. Hydraulic failure is hypothesized to occur if drought intensity is sufficient to push a plant past its threshold for irreversible desiccation before carbon starvation occurs. Biotic agents, such as insects and pathogens, can amplify or be amplified by both carbon starvation and hydraulic failure (from McDowell et al., 2008 p 722).

This model can be applied to the example of Perth's Araucaria heterophylla (Norfolk Island Pine), many of which have been declining. Surveys of 200 Norfolk Island Pine trees were carried out in 2009 and 2010. Samples were collected and morphological characteristics of the consistently isolated fungus analysed. The isolated fungus was identified as Neofusicoccum parvum (Hossein & Burgess, 2011). These Botryosphaeriaceae are common endophytes of a wide variety of woody plants worldwide. Diseases associated with the Botryosphaeriaceae are often stress related requiring a predisposing incident to trigger disease expression. Environmental stresses include drought, extreme temperature fluctuations, nutrient deficiencies and mechanical injuries (Hossein & Burgess, 2011). As well as the decline of the A. heterophylla are reports of the indigenous Melaleuca lanceolata (Rottnest Island Tea Tree) declining and dieing along the North Fremantle foreshore as a result of a Botryosphaeiraceae endophyte during one of Perths driest winters on record in 2010 (Barber, 2011).

Given the research presented in this paper, along with the changing climate, there needs to be further research into paving materials suitable for paths, road ways and other urban infrastructure that do not reradiate as much heat as the commonly used asphalt and concrete. The results of that research needs to be provided to the landscaping industry (including landscape architects) and local government who recommend and use these paving types and other hard surfaces. Finally, there should always be better scrutiny of tree species selection for paved urban environments, particularly given climate change predictions, population increase in the urban environment, together with the conditions favouring antagonistic and pathogenic biotic agent demographics. This scrutiny requires effort by the academic researchers, end users (industry) and tree suppliers – nurserymen.

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AVENUES OF HONOUR 1915-2015 PROJECT

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Background

The Avenues of Honour 1915-2015 project is a national initiative to honour with a tree the memory of every individual who has made the supreme sacrifice on behalf of all Australians, by documenting, preserving and reinstating the original, and establishing new Avenues of Honour, during the Centenary of World War I in the period April 25th 2015 through to November 11th 2018. The Project was launched at the 5th National TREENET Symposium in 2004. (1)

The arboreal Avenue of Honour has been an enduring and highly popular form of public commemoration of military service in Australia. More than any other nation, Australians have chosen to recognise service and sacrifice through community plantings of memorial Avenues of Honour. The earliest recorded Avenues of Honour were created in response to Australia's participation in the Boer War, but the majority were established during and after World War I and, to a lesser extent, World War II.

At the time Sarah Cockerell listed 185 avenues as surviving in some form (2) but after a nationwide survey in 2006 she recorded 567 known Avenues of Honour across Australia, most of which remained in some form, although some were depleted or in poor condition. Across all of the existing Avenues there are estimated to be more than 100 000 living trees. These Avenues and the trees that comprise them are typically on public land and, most often, are managed by Local Councils, although Avenues may also have dedicated local management committees.

Known Avenues of Honour by State, as of 2006

State	Number identified
ACT	2
NSW	67
QLD	52
SA	38
TAS	69
VIC	312
WA	27
TOTAL	**567**

Purpose

The purpose of the Avenues of Honour 2015 project is to ensure that Avenues continue to play an important role in community commemoration of military service and sacrifice. A particular goal for the Anzac Centenary is to ensure that each of those Australians who made the supreme sacrifice in serving their country are recognised with a thriving living memorial that is known, recognised and discoverable by their descendants, relatives and by local communities as well as by any other interested parties.

Project Scope

The TREENET Avenues of Honour project provides national leadership and co-ordination of community-based initiatives to restore, reinstate and establish memorial Avenues of Honour to coincide with the Anzac Centenary and the 100th anniversary of the major events of World War I over the period 1914-1918.

The project will undertake research and documentation of existing Avenues, creating a comprehensive and accessible online record of all Avenues using the latest social and mobile web technologies and providing advice and support to local communities to restore, reinstate or establish Avenues of Honour as part of their commemorations of the Anzac Centenary and the 100th Anniversary of the events of World War I.

The project is using contemporary web-based technologies to create an enduring and comprehensive national online record of existing, planned and lost Avenues as a precursor to the engagement of local communities in their preservation, restoration and establishment anytime in the future.

Over 5 years, the project will complete the task of documenting all avenues, trees and persons commemorated, provide assistance and training to local communities to research document and promote their avenues and provide technical advice and support in the restoration of existing avenues and the establishment of new ones.

There are three main areas of project activity (see the project plan at Section 7 for details)

1. **Research and documentation**
   Developing and managing an integrated national online reference service for Australia's Avenues of Honour covering their history, significance, current condition and future management and sustainability.

2. **Community engagement**
   Inspiring local communities to recognise the value of their existing living memorials and to undertake restoration and planting initiatives as a national community-based commemoration for the Centenary of Anzac and the 100th anniversary of events during World War I.

3. **Supporting community activities**
   Providing standard operating procedures for undertaking Avenue projects at the community level as well as technical assessment and advice in specialist areas relating to trees, historical data, information sharing and commemorative protocol.

Outcomes

The project aims to deliver outcomes in the short term during the course of the project and in the long term by building sustainable online information resources and local communities of interest to support Avenues of Honour into the future. In particular, the project will achieve:

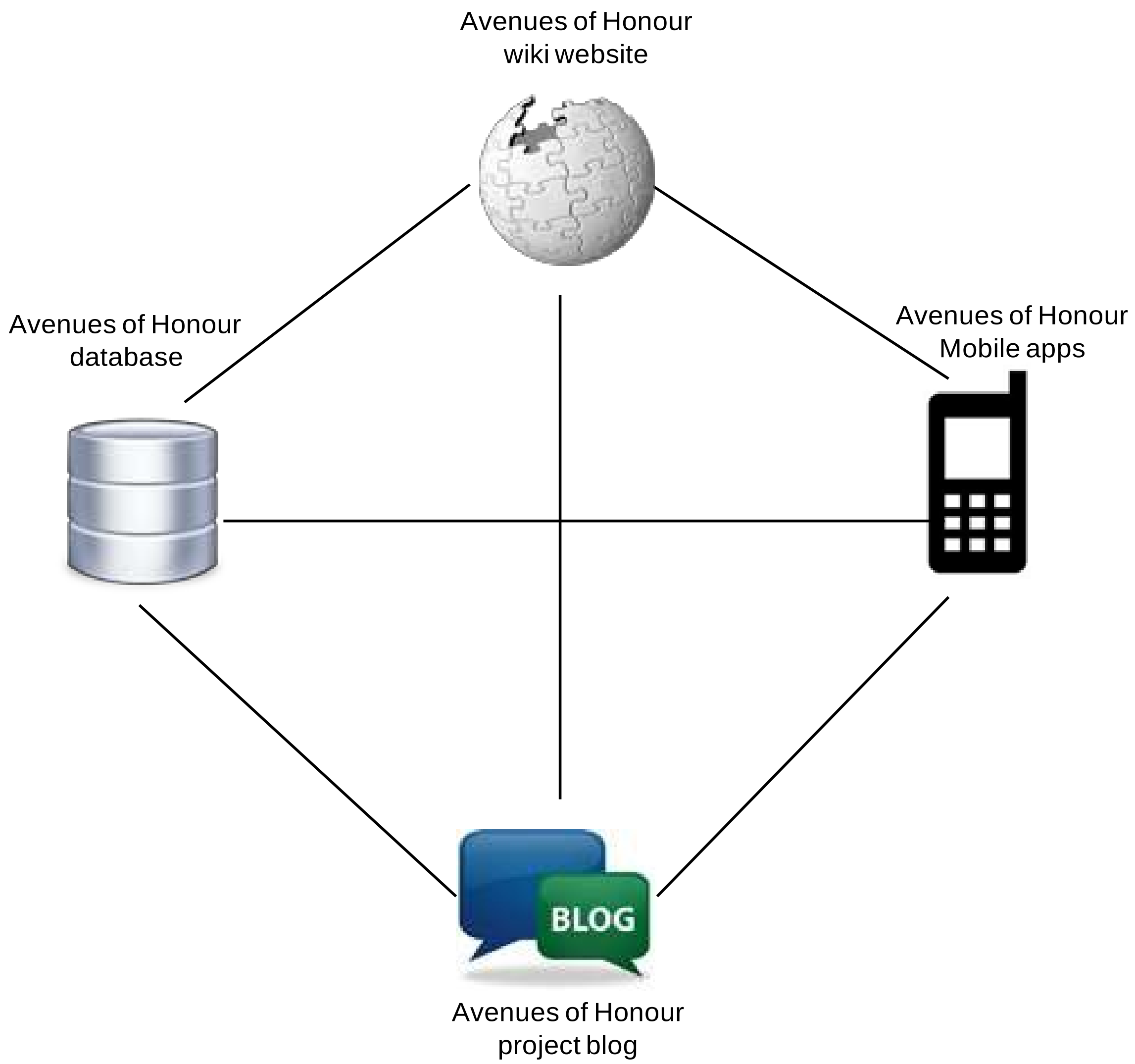
- Increased public awareness and appreciation of Avenues of Honour as a record and monument to military service and sacrifice.
- An integrated national web-based information resource about Avenues of Honours and the people and service they commemorate.
- Sustainable local communities of interest around each Avenue
- Improvement in the long term health and sustainability of Australia's Avenues of Honour.
- New investment in commemorative plantings.
- Enhanced community engagement through commemoration activities associated with the Avenues during the Anzac Centenary and the 100th Anniversary of the events of World War I.
- Increased accessibility of local history records about the experience of Australia's service men and women.
- Improving management practices for public arboreal projects.
- Education, public awareness and community access.

Technical development

The project requires the development of technologically-based products and infrastructure to capture, store and publish information about Avenues of Honour and to make it accessible to communities, families, researchers and students. This infrastructure is at the heart of the project as it brings together for the first time all information about Australia's Avenues of Honour and the people and service that they commemorate. The project will commission and manage the development of an integrated technical infrastructure that will support community participation in the creation and sharing of information about the avenues and in creating and sharing the memories of communities and families about those who served.

In 2013, the technical infrastructure to support the project was scoped and development was undertaken on data requirements by Sociable Technology. The first component, the Avenues of Honour project blog, was launched in June.

There are four main components for the technical infrastructure

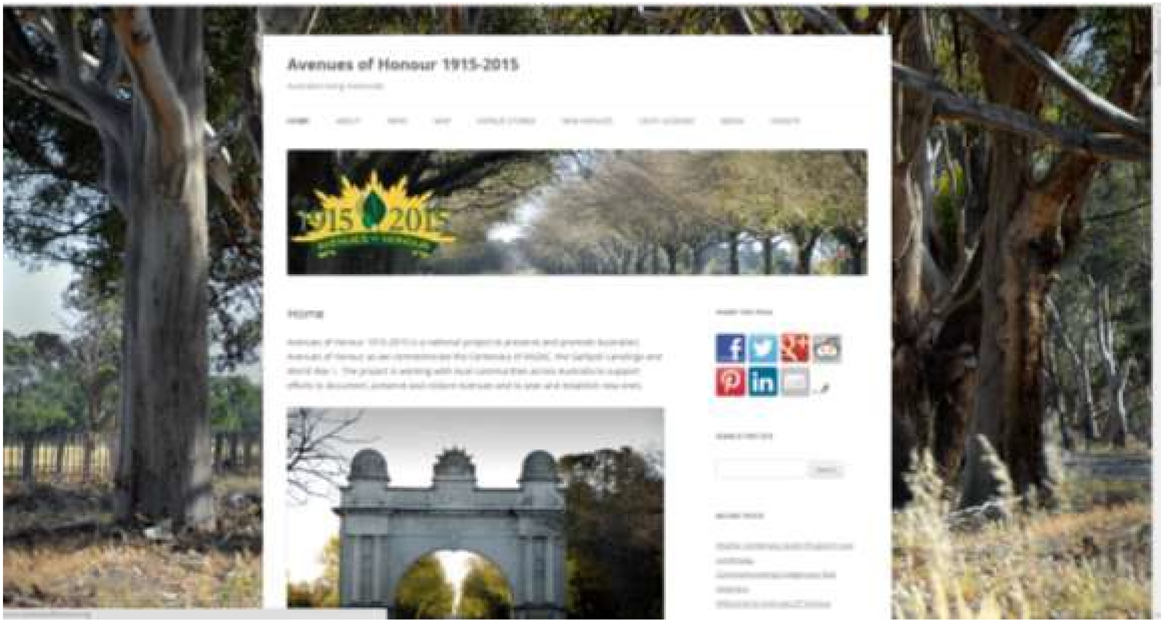


The Avenues of Honour wiki website will, on completion, create a national community-sourced encyclopedia of information about the Avenues and the people and service they commemorate. The use of wiki technology enables people across Australia to add information and memories about the Avenues and the people associated with them. The website will become an indispensable permanent online reference to the history and health of every Avenue.

Mobile applications will assist in the capture of information about Avenues, plaques and trees in the research phase and provide information from the wiki website for mobile devices such as phones, tablets and GPS devices.

The project blog launched in April 2013 will document and promote the project over 5 years to keep participants informed and engaged. The blog integrates with social media platforms and e-newsletters to promote the Avenues project and document its progress and successes.

Avenues of Honour project blog site, launched June 2013 at www.avenuesofhonour.org



The Avenues of Honour database will maintain a full data record of each Avenue for the purpose of supporting effective planning and future management of Australia's Avenues.

There are many fields of information that should be captured if possible for each tree or Avenue. At the 2007 TREENET Symposium Ben Kenyon (3) presented a draft standard for the Avenues of Honour database which has been a key document in the design of the currently proposed database.

In planning for the technical infrastructure to support the online presence of the Avenues of Honour project, the data standard has been updated and extended.

Data standard for Avenues of Honour Project, December 2012

This data standard identifies the data fields to be used in the master database and wiki website. Relationships between the fields are built into the data model.

The standard is divided into 6 parts, covering:

1. Avenues
2. Trees
3. Plaques
4. Persons Commemorated
5. Species
6. Contacts

1. AVENUES

Field ID	Field
	Identification fields
101	Avenue ID Number
102	Avenue Type
103	Avenue Name
104	Street Address
105	Locality name
106	State/Territory

107	Postcode
108	Geo-cordinates
109	Location details
110	Local Government Area (LGA)
111	State/Territory electorate
112	Federal electorate
	Description fields
113	Date of planting
114	Planted by
115	Designed by
116	Original total number of trees
117	Existing number of trees
118	Proposed number of trees
119	Avenue length
120	Description
121	Original features
122	Notes
123	Species
124	Signage
125	Plaques
	Significance fields
126	Conflict/s commemorated
127	Original purpose
128	Recognition
129	History
130	References
	Management fields
131	Managing authority
132	Managing authority contact person
133	Associated groups
134	Condition assessment
135	Major changes over time
136	Known Hazards
137	Donors
138	Local management issues
	Audio visual fields
139	Photographs
140	Audio
141	Video

2. TREES

Identification fields

201	Tree ID number
202	Avenue Name
203	Geo-cordinates
204	Plaque

Description fields

205	Genus
206	Species
207	Sub species
208	Date planted
209	Person/People Commemorated

Condition fields

210	Age
211	Height
212	Diameter at Breast Height (DBH)
213	Health
214	Structure
215	Useful life expectancy
216	Likely works
217	Assessed by
218	Assessed on

Audio visual fields

219	Photographs
220	Audio
221	Video

3. PLAQUES

Identification fields

301	Plaque ID number
302	Tree ID
303	Avenue name
304	Plaque location
305	Plaque orientation
306	Plaque geo-cordinates
307	Plaque material
308	Plaque condition
309	Plaque Manufacturer

Audio visual fields

310	Photographs

4. PERSON/PEOPLE COMMEMORATED

Field ID	Field
	Identification fields
	Individual/Group
401	Surname
402	Also known as
403	First name
404	Other names
405	Service ID
406	Rank
407	Date of birth
408	Place of birth
409	Date of decease
410	Place of decease
	Service history
411	Date of enlisting
412	Place of enlisting
413	Service
414	Unit name
415	Conflict
416	Deployments
417	Died on active service
418	Date of decease
419	NAA Enlistment Record
420	NAA Service Record
421	AWM Roll of Honour
422	Date of embarkation
423	Place of embarkation
424	Name of Embarkation ship
425	
	Contact information
426	Next of kin (enlistment record)
427	Known kin relative
428	Historical information contact
	Audio visual fields
429	Photographs
430	Audio
431	Video

5. SPECIES

Field ID	Field
	Identification fields
501	Species
502	Common name
503	Height
504	Longevity
	Audio visual fields
505	Photographs

6. CONTACTS

Field ID	Field
601	Avenue ID
602	Tree ID
603	Service ID
604	Type of contact
605	Title
606	Contact person surname
607	Contact person first name
608	Organisation
609	Postal address
609	Phone
610	Email
611	Web address

Participation and promotion

The Avenues of Honour project is based on widespread public participation which requires engagement with a broad range of project stakeholders.

The following stakeholder map outlines the key stakeholder groups in the project. A stakeholder engagement strategy will be developed as part of the project's Marketing and Communication Plan.

Stakeholder map

Individual or Group	Nature of Stakeholding	Issues of interest and concern
TREENET, Adelaide	Project Manager Expert Arborist advice	Preservation of existing Avenues Establishment of new Avenues Raising awareness of urban arboriculture
Local Councils, 562 local government bodies and State and National peak bodies	Management of Avenues Community development Local commemoration of Anzac Centenary	Maintenance of Avenues Community participation Cost benefit of establishing/maintaining avenues
RSL and other service organisations, 1300 RSL local sub-branches, state branches, national peak bodies, approximately 180 000 members	Preservation of existing memorials Recognition of service and sacrifice Community education and participation	Appropriate recognition and commemoration in memorials and events
Arborist and landscape professionals	Preserving and promoting urban arboriculture	Maintaining existing avenues Establishing future sustainability
Commonwealth, State and Territory Governments	Effective commemoration of Anzac Centenary Funding and leadership of commemoration activities	Participation in commemoration activities Cost effectiveness Recognition of government activity/services
Australian War Memorial	Leading organisation for commemoration of Australian military service	Effective commemoration of Anzac Centenary
Local communities	Recognition of local contribution Preservation of existing memorials	Appropriate commemoration activities and memorials
Relatives and descendants of persons commemorated	Living connection to those who served and died. Public remembrance and respect.	Appropriate commemoration activities and memorials Opportunities to participate.
National Trust and other Heritage bodies, including government agencies Local, state and national organisations and peak bodies	Protection and preservation of natural and cultural heritage Promotion of heritage and community engagement	Recording and listing Avenues for heritage protection Increasing awareness of Avenues as local heritage

Individual or Group	Nature of Stakeholding	Issues of interest and concern
Community historical societies 1000 local history organisations with 100 000 members; State and national organisations and peak bodies	Documenting local history including the history of military service Promoting local heritage sites and community interest in history	Connecting Avenues to local history records Ensuring that local history is preserved and accessible Public events to promote interest in local history
School educators, Curriculum experts, subject associations and peak bodies.	Educating students about history and the environment	Accessible information to support teaching and learning Opportunities for student activities and participation.

Participants

The project aims to engage people across Australia as participants in researching, documenting, restoring, creating and celebrating Avenues of Honour in their communities.

Research

The research stage of the project will consolidate information about existing Avenues into a single national database and make it available to people via the wiki website and mobile applications. The project will work in partnership with the Federation of Australian Historical Societies and the Australian Council of National Trusts to engage local history and heritage organisations in the project as on the ground researchers and contributors to the project.

Community engagement

Community engagement activities will happen in collaboration with Local Councils, RSL organisations, Local Historical Societies and National Trust organisations and in conjunction with schools and other community organisations. The project will establish community partnerships around each Avenue and support them with training and information to enable them to record and promote the history and significance of local Avenues.

Marketing and Communication

The project will develop a national marketing and communication strategy to promote the goals and successes of the project through print broadcast media and online through the project blog, social media platforms and e-newsletter. The communication strategy will ensure that local community groups are in touch with each other to promote shared interest and learning across Australia.

Sponsorship and fundraising

The project depends on significant funding being raised through sponsorship and fundraising activities. A sponsorship strategy will be developed to identify suitable sponsors to approach for support. A presentation to potential major sponsors and supporters will be developed for sponsor approaches to be undertaken in the first half of 2013.

The project will also be nominating for funding under Australian Government Anzac Centenary activities.

Education and public programs

The project will develop education resource materials in line with the new Australian Curriculum to support teachers in promoting learning and participation in the Avenues of Honour project within primary and secondary schools. Communities that partner with the program will be able to participate in workshop sessions on promoting participation in the Avenues program.

Conclusion

Through the use of new communications technology, the Avenues of Honour project is now positioned to enter a new phase of public promotion and community engagement. The establishment of the project blog site in 2013, presenting the current data held by TREENET about known Avenues has significantly raised the profile of the project and brought forth new information and a groundswell of public interest and support.

The finalisation of the data standard to inform the future development of a wiki based website and supporting mobile applications means we are also ready to enter the next stage of documentation and promotion of existing Avenues. This will build momentum for restoration and replanting activity and for the creation of new Avenues to coincide with the 100th Anniversary of World War I and the Gallipoli landings.

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QUANTIFYING OUR ARBORICULTURAL LEGACY – ANALYSIS OF AGE CLASS DISTRIBUTIONS.

Dave Williams
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Introduction

The majority of street trees that provide an impact in the landscape result from decision making processes conducted many years in the past. It is important to identify whether current decision making processes will leave a similar legacy for future generations.

Many large land managers today maintain an inventory of their street tree assets. It would appear that the primary drivers for conducting a tree inventory, in most cases, relate to risk management and works scheduling (Keller and Konijnendijk 2012). While these are arguably essential to the management of large populations of trees there is much more that can be determined from the information collected. To date most of the published analysis of inventory data concerns the species diversity (e.g. Frank et al. 2006, Ningal et al. 2010, Thaiutsa et al. 2008) or the dimensions of the trees (e.g. Ningal et al. 2010, Thaiutsa et al. 2008). This paper aims to investigate one potential methodology for analysing inventory data to evaluate the overall sustainability of the tree population.

In the context of an urban environment there are many reasons why trees may require removal including risk mitigation, infrastructure works, aesthetics, vandalism, etc. It is rare that any removal of trees are conducted prior to there being a necessity to do so, a common goal of street tree management is an increase in the size of trees (Ordóñez and Duniker 2013) which is not consistent with proactive tree removals. While an admirable ideal, if the retention of large/old trees is a tree management driver it is possible that a situation is created where a large proportion of the tree asset will require removal in a short space of time. If we are to provide an equivalent benefit from our street trees to all future generations then appropriate proactive tree removals may be justified.

There have been attempts to promote a variety of age classes within a tree population to prevent large scale removals based on mortality, such as Kirnbauer et al. 2009, however (in particular the cited paper) this relates to establishing a planting program to promote this variety rather than an analysis of the existing population.

In bushfire planning and management one approach to ensuring ecologically sustainable fire regimes in a landscape unit is based around the concept of theoretical age class distributions. The fundamental principle is that in order to achieve older age classes of vegetation there must be proportionally more younger age classes to account for an increasing probability of disturbance as the vegetation community ages. It is not intended in this paper to assess this method in relation to its appropriateness in the context of bushfire planning and management.

It is expected that with some modifications this method can be used to analyse existing tree populations and provide guidance on tree removal and planting management.

Method

The likelihood of a tree requiring removal at a certain age may be represented by a notional “Hazard Function” where the probability of removal varies with the age of the tree. In the example (Figure One) the assumption is that when a street tree is in the first few years of life there is an increased probability of removal due to factors such as transplant shock, followed by a period of lower probability of removal while the tree remains vigorous and the final stages where the tree is more likely to require removal due to mortality. The area under this curve will equal a probability of 1.0, i.e. after a period of time (in this example 100 years) all of the trees in this or greater age classes will have been removed. If the removal of trees follows the function in Figure One then the age class distribution is likely to look something like that in Figure Two. It should be noted that it is assumed that removed trees are replaced almost immediately.

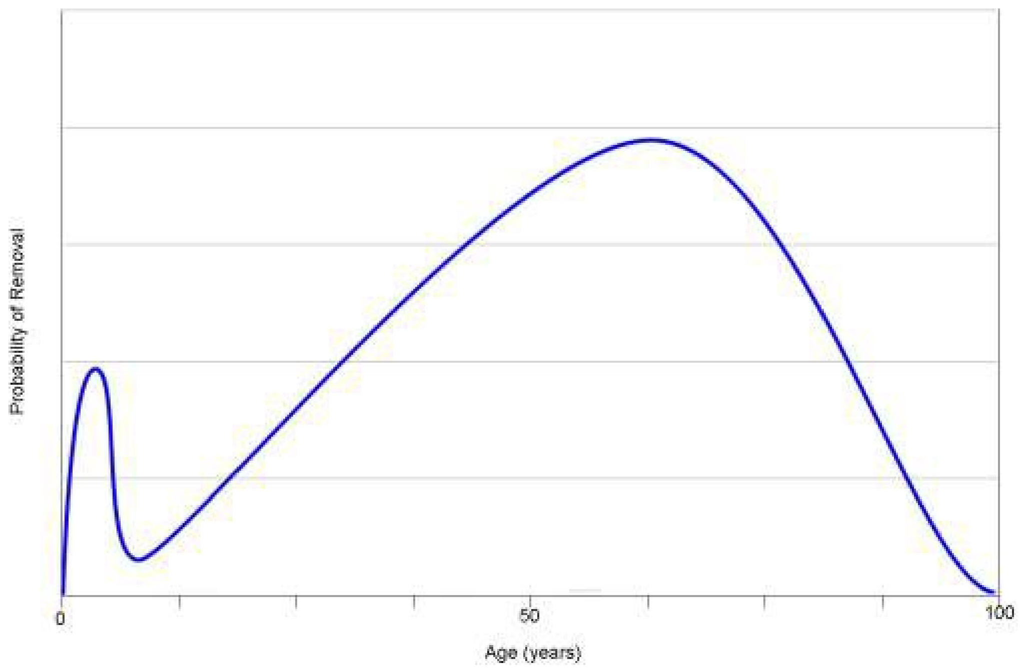


Figure 1. Theoretical Hazard Function

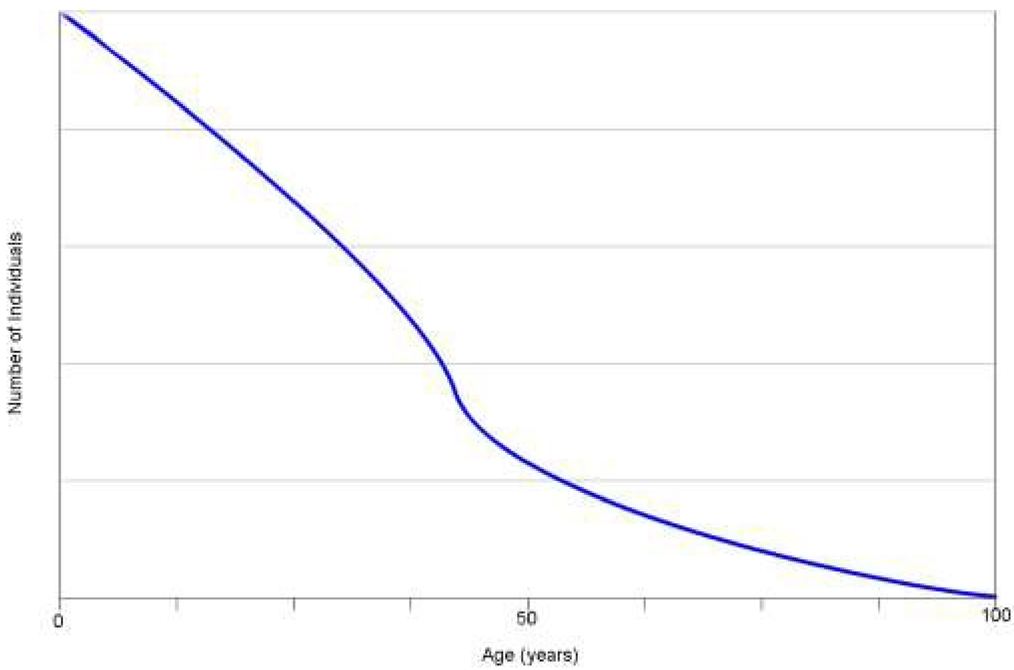


Figure 2. Variable Hazard Function Age Class Distribution

It may be possible to conduct further investigation to make this notional hazard function more accurate, however this would involve a much higher level of data capture that may not be justified by an increase in 'usefulness' of this model.

The simplest form of hazard function is one where there is an equal probability of a tree requiring removal at any age. Using this function the age class distribution in a tree population will be represented by a negative exponential curve (see Figure Three). Figure Four shows that for practical purposes using either hazard function the result is similar and as the mathematics of a constant hazard function is much easier it is the one used as the starting point for this analysis.

The formula for the negative exponential curve representing the age classes takes the form:

$$a_t = b e^{kt}$$

Where:

a	= the number of individuals present at time *t*
t	= the age class in years
b and *k*	= constants

In order to make practical use of the above some values must be known:

Total Tree Population (a_{total})	- the total number of individuals in the tree population
Annual Tree Removals (*r*)	- the number of trees removed from the population annually
Tree Removal Cycle (*c*)	- is the number of years taken to remove a number of trees equivalent to that of the total tree population
Maximum Life Span (*m*)	- is the maximum amount of time a tree is likely to exist in a street

The average number of individuals in the first age class period (assuming a 1 year age class period) will be equal to the average number of trees removed each year. The average number of individuals in the last age class period will equal $\frac{\square}{m} \times \frac{a_{total}}{m}$. By using the number of individuals in the first age class (a_{first}) and the number of individuals in the final age class (a_{last}) the above formula can be resolved.

Once the formula has been resolved the theoretical number of individuals can be calculated and compared to field data or planting records to identify where certain age classes are appropriately, under or over represented within the population.

Case Study

To illustrate this concept data from the Shire of Macedon Ranges were analysed. The data were collected as part of a risk mitigation and works scheduling inventory conducted in 2011. The age of each tree were captured into estimated ranges.

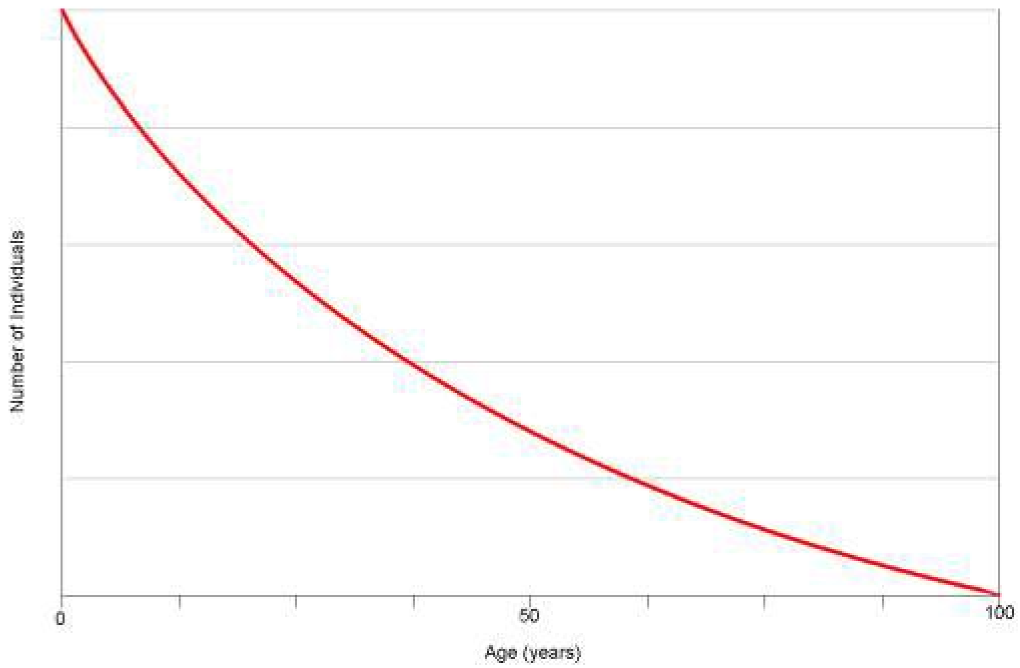


Figure 3. Constant Hazard Function Age Class Distribution

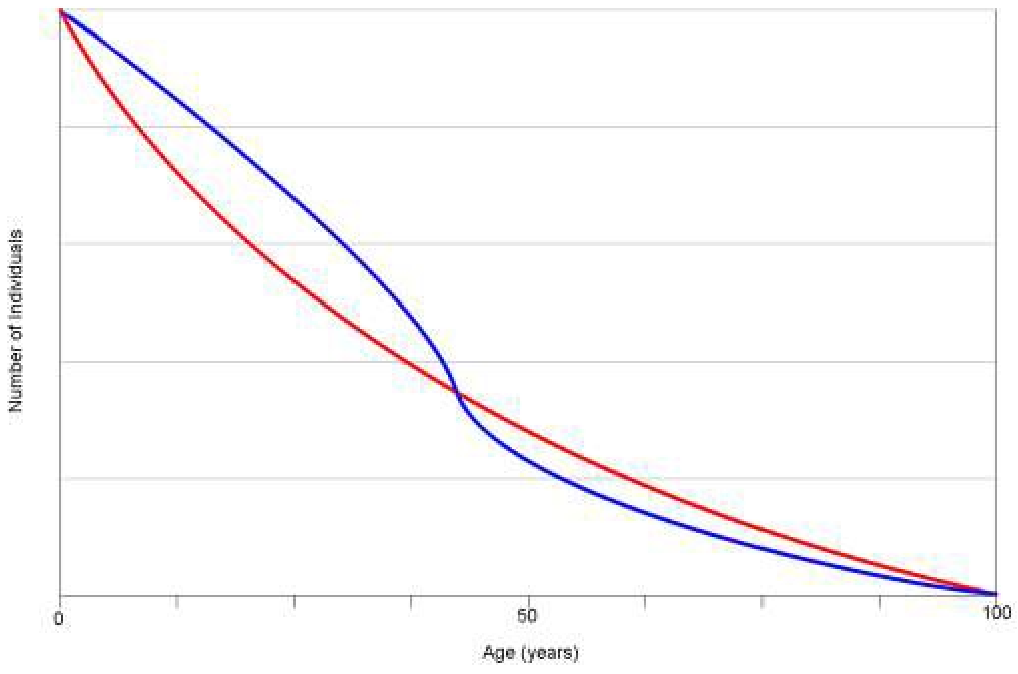


Figure 4. Variable & Constant Hazard Function Age Class Distribution

The following is known about the tree population:

Total Tree Population (a_{total}) = 27,485

Annual Tree Removals (*r*) = 500

Tree Removal Cycle (*c*) = 55

Maximum Life Span (*m*) = 100

From this we can see that:

$$a_{first} = 500$$

and

$$a_{last} = \frac{55}{100} \times \frac{27485}{100} = 151$$

To resolve the original formula we use the fact that:

(from a_{first})

$$500 = b\mathrm{e}^{k \times 1}$$

$$b = \frac{500}{\mathrm{e}^{k}}$$

And

(from a_{last})

$$151 = b\mathrm{e}^{k \times 100}$$

Therefore

$$151 = \frac{500}{\mathrm{e}^{k}} \times \mathrm{e}^{100k}$$

$$151 = 500\mathrm{e}^{99k}$$

$$\ln(151) = \ln(500\mathrm{e}^{99k})$$

$$\ln 151 = \ln 500 + \ln(\mathrm{e}^{99k})$$

$$99k = \ln 151 - \ln 500$$

$$k = \frac{5.01728 - 6.21461}{99}$$

$$k = -0.0121$$

Then

$$b = \frac{500}{\mathrm{e}^{-0.0121}}$$

$$b = 506.088$$

The formula to calculate the theoretical number of individuals (*a*) at a given time (*t*) in the Shire of Macedon Ranges is:

$$a_t = 506.088\mathrm{e}^{-0.0121t}$$

We can then use a spreadsheet to calculate the theoretical numbers of individuals within a given age class to compare it to the field data. Figure Five shows the comparison from the data collected during the inventory and the calculation of the theoretical numbers of individuals.

The analysis of the data suggests that the Shire of Macedon Ranges is over represented in the Less than 10 years and 10-20 years age classes and underrepresented in the 20-50 years, 50-80 years and 80+ years age classes.

While there is very little that can be done to rectify these figures in the short term as it is not possible to establish 20+ year old trees on a large scale, there may be an issue with tree survival after 20 years that has caused this imbalance and would be worth investigating. For example, a large proportion of the trees in the Less than 10 years age class are natural regeneration in rural roadsides and it may be that after 20 years competition between individuals' results in a significantly higher mortality rate.

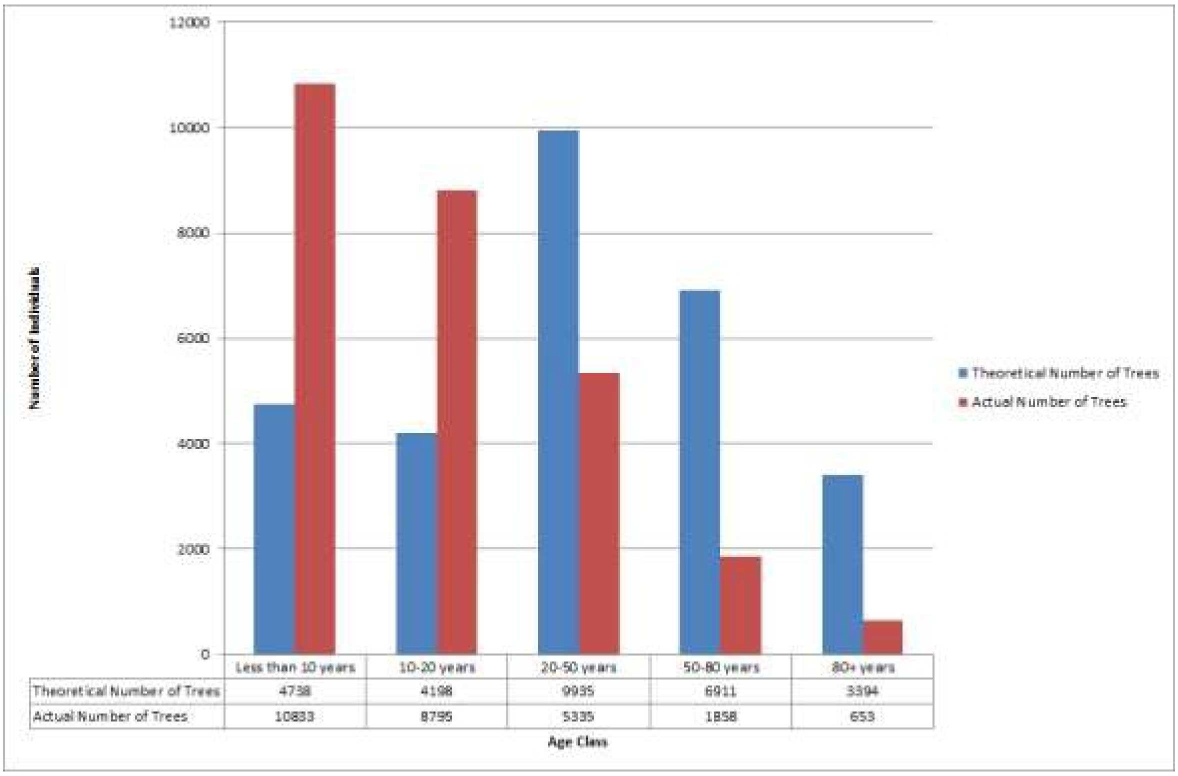
Discussion

The aim of this paper was not to provide a detailed analysis of a particular municipal tree population but rather to explain and demonstrate a particular type of analysis. To that end there are several assumptions that we must be mindful of while interpreting the results of the analysis. These include:

- The analysis is based on the assumption that all available planting spaces are filled. In most municipal areas this is unlikely to be true, however if the vacant spaces are excluded from the analysis the results are still valid.
- It is difficult to estimate the age of a tree. This can be overcome by using wide age class ranges that decrease the likelihood of miscategorisation. It also highlights the usefulness of recording planting year for all future plantings.

This type of analysis is not intended to drive wholesale tree removals from within age classes to try and even up the theoretical balance, but following the normal routine tree removals in a municipality there may be an opportunity for the removal of an appropriate number of the worst specimens from an over represented age class. In conjunction with other available information this could be a tool that contributes to the sustainability of the tree population.

Provided the assumptions and limitations of any input data are acknowledged and accounted for in the analysis, simple models such as this one can provide great insights into the current state of the tree population and likely future scenarios.



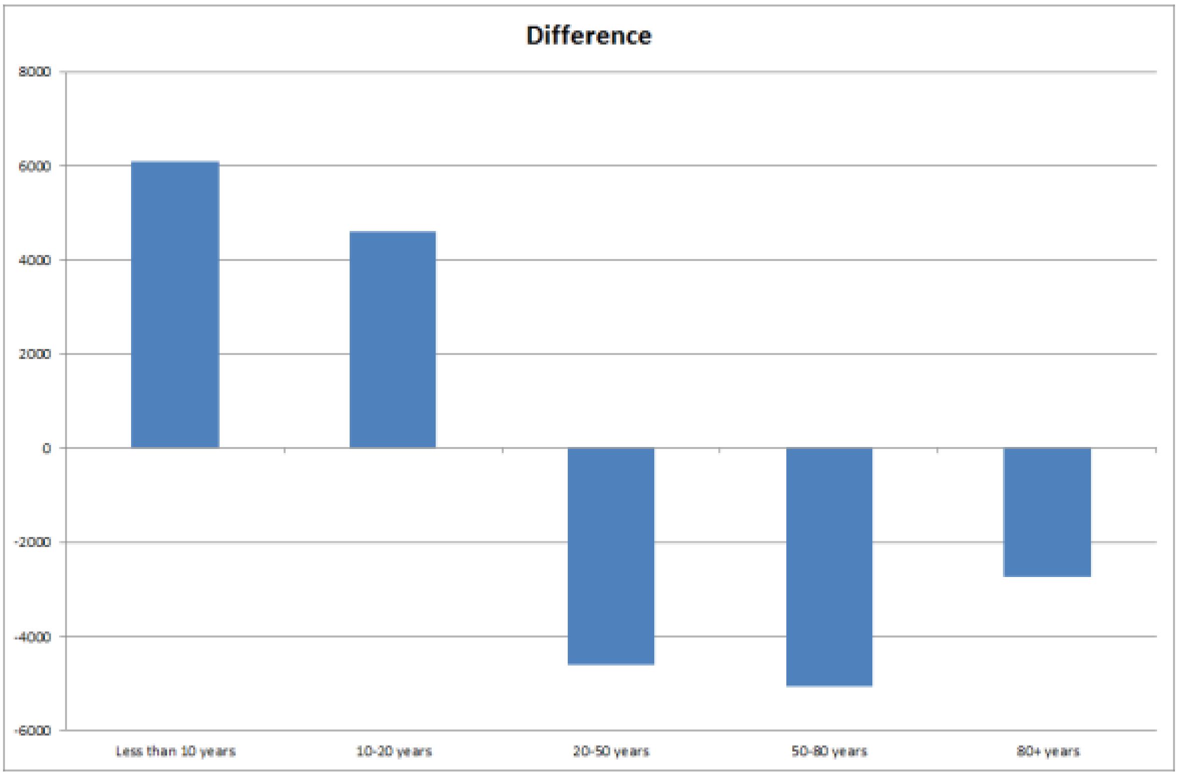


Figure 5. Shire of Macedon Ranges- Theoretical vs. Actual Tree Numbers

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RING-BARKING AND GIRDLING: HOW MUCH VASCULAR CONNECTION DO YOU NEED BETWEEN ROOTS AND CROWN?

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Abstract
Girdling and ring-barking of trees occurs for many reasons - vehicle impact, grazing by animals, insect and fungal attack and human vandalism. Ring-barking that removes only phloem and cambial tissue has a vastly different impact on tree physiology than girdling which removes phloem, cambial and xylem tissue. Girdling has an almost immediate effect on transpiration and so plants wilt quickly and tissues can die within days. Ring-barking however effects translocation and so causes a slow starvation of the root system and can take many months or even years before root tissues start to die from starvation and the tree wilts and dies.

Many trees survive partial ring-barking, but how much of the vascular tissue needs to be intact for plants to survive and what effective treatments are available, if any, to arborists for improving the chances of tree survival? As little as 10% of vascular tissue may be all that is required for an otherwise healthy and vigorous young tree to survive and recover. Furthermore, while ring-barking and girdling may not kill a tree they may leave it vulnerable to attack from insect pests and fungal diseases.

Tree management techniques such as bridge, approach or patch grafting may be considered as remedial treatments for ring-barked or girdled trees. Soil injection of sugar solutions may also be of benefit. However, making sure that the tree is free from environmental stresses and pest and diseases are important to recovery and allowing time for the tree to produce callus and wound wood.

Introduction
It is unfortunate the terms girdling, ring barking, ring-barking, ringbarking (ring-barking with the hyphen seems to about twice as common in use as ringbarking) and even ringing are used as synonyms to refer to the removal of a band or strip of bark which contains the cork and cork cambium, phloem and usually the cambium around the entire circumference of a tree (Salisbury and Ross, 1992; Raven et al, 2005). It is unfortunate that so many terms are used for the same imprecisely specified action, as the depth to which the band of tissue is cut can markedly affect the impact on the tree's vascular system and the subsequent effect on the tree of the action.

In this paper, ring-barking will be defined as a circumferential cut made around the trunk of a tree which removes a band of tissue to the depth of an including the cambium. Such a cut removes a band which contains cork and cork cambium, phloem tissues and the cambium and so has an immediate impact on the translocation of materials in the phloem tissues. Girdling will be defined as a circumferential cut made around the trunk of a tree which removes a band of tissue to the depth of the active or functional xylem tissues. Such a cut removes a band which contains cork and cork cambium, phloem tissues, the cambium and the current season's active or functional xylem tissue growth ring and so has an immediate impact on both the translocational and transpirational processes. The only way of telling whether a tree has been ring-barked or girdled is to examine the tissues which have been severed.

Because the effects and consequences of ring-barking and girdling on trees are so different and impact on the tree over such different time scales, it would probably be wise if different terms were adopted for the different actions. Such a distinction would bring clarity of meaning to the terms, aid in diagnosis of injury to trees, avoid ambiguity, aid in defining remedial treatment and benefit the legal system in matters related to litigation involving either activity.

Causes of Ring-barking and Girdling
There are many different causes of ring-barking and girdling from both natural and human interventions (Table 1). Both ring-barking and girdling have a long history of being used as management tools in forestry and agriculture for clearing land and removing trees from paddocks (Stubbs, 1998). It is cost effective for

selectively thinning forests and plantations and for the control of invasive woody species (Kilroy and Windell, 1999). In more subtle ways, orchardists and horticulturists have used ring-barking and girdling to manipulate plant growth form, soluble sugar content and fruit yield and production, but they are careful not to completely ring-bark the whole stem or selected branch (Hartmann et al, 1981; Goren et al, 2004).

In urban arboriculture, the most common causes of ring-barking and girdling arise from accidents, poor landscape management practices and attempts to kill trees. Accidental occurrences include motor vehicle accidents and wire and other non-degradable materials tied around tree trunks. Poor landscape management practices such as girdling roots from poor propagation technique, mower and whippersnipper damage, poor staking and tree guards, and pavement and concrete surrounding trunks in paved areas can all cause serious damage. Finally, there are attempts at killing trees in disputes between neighbours and acts of deliberate vandalism (Harris et al, 2004).

Not all ring-barking and girdling damage, however, is caused by human action as animal grazing, fungal and insect attack and poor root growth habit can occur naturally. While these cases are not all that common, damage by sulphur-crested cockatoos (*Cacatua galerita*) can be extensive and cause significant structural damage to large trees. Horses have also been known to ring-bark large trees in their paddocks by grazing the bark in great strips, apparently to meet a nutrient deficiency. Insect and fungal damage to trunks and large limbs is not uncommon, but usually affects trees that are already stressed.

The physiology of Ring-barking and Girdling

Ring-barking affecting phloem tissues and transport:

The effects of ring-barking, as defined earlier, on the physiology of a tree are dramatically different from the effects of girdling. The removal of the bark and cambium only has an impact on translocation via the phloem tissues, but water and nutrient transport continues as xylem tissues are undamaged (Weier et al, 1982; Salisbury and Ross 1992). The removal of phloem tissues affects transport of complex organic molecules such as sugars, amino acids and hormones, as well as other simpler substances dissolved in the phloem sap (Holmes, 1984). Transport of these substances from roots to foliage and stem above the region ring-barked is halted but so too is transport from the foliage to the root system, especially of photosynthates and hormones.

The direction of transport through phloem tissues and its impact on tree physiology can also vary according to the seasons. During periods of active growth when photosynthetic activity is high, transport is often predominantly basipetal from foliage to roots. However, in deciduous species coming out of dormancy in early spring, transport may be predominantly acropetal as carbohydrate stored in the roots and trunks is mobilized to facilitate bud burst and leaf production. Translocation and phloem transport is symplastic movement of substances through the interconnected cytoplasm of interconnected living cells (Salisbury and Ross, 1992).

The ratio of the amount of phloem tissue to xylem tissue may be as high as 1 to 4, but is more usually about 1 to 6 and in many tree species is closer to 1 to 10 (Fahn, 1975). The velocity of the movement of solutes through the phloem over long distances can be quite rapid, varying from about 100 – 1000 mm per hour (Fahn 1975, Salisbury and Ross 1992; Atwell et al, 1999) with sieve tube cells emptying between 3 to 10 times per second (Fahn, 1975; Salisbury and Ross 1992; Atwell et al, 1999). Interruption to phloem transport by ring-barking and girdling would lead to rapid depletion of carbohydrates.

Table 1. Some natural and human causes of ring-barking and/or girdling

Human caused Ring-barking/Girdling	**Naturally caused Ring-barking/Girdling**
Agricultural killing of trees to clear paddocks	Grazing by animals, particularly horses
Foresters killing selected trees to thin stands	Stripping of bark by birds, such as cockatoos
Orchardists killing branches and controlling vegetative growth	Tunneling insects under the bark grazing on bark and cambial tissues to excess
Orchardists controlling fruit, yield, size and sugar content	Fungal diseases, such as collar rot
Placement of wires and nylon ropes around tree trunks and branches	Circling or girdling roots which can occur naturally, as well as from poor nursery propagation
Unintended damage from use of poor staking	Trunk damage from rocks, such as in trees germinating in crevices
Unintended damage from mowers and whippersnippers	Bark eating rodents
Unintended root girdling of the stem by roots due to poor propagation and/or planting techniques	
Accidental damage from motor vehicle impact	
Unintended damage from construction works	
Deliberate vandalism to trunk and branches	
Unintended trunk damage from pavements and hard surfaces	

The most immediate effect of these changes in transport is that hormones synthesised in the roots no longer travel above the zone of ring-barking and those produced by the foliage no longer reach the roots below. Often it is the interaction of different hormones at appropriate concentrations that affect the physiological responses and so root and shoot growth and development can be impacted. Over the longer term, however, it is the failure of photosynthate to reach the root system that has significant consequences that can kill the tree.

For some time after damage, growth and both branch and trunk incremental increases above the zone of ring-barking continue. Indeed foliage condition may improve and incremental growth rates increase as all of the carbohydrate produced by the foliage remains in the region of the trunk and canopy, as none is able to reach the root system. So the trunk above the ring-barked zone increases in girth and there is often a noticeable swelling above the ring-barking cut. Growth below the cut slows and eventually ceases and so an obvious difference develops in the trunk diameters above and below the ring-barking zone (Figure 1).

Immediately after ring-barking, most trees have sufficient carbohydrate reserves in the root cells to maintain an active cell metabolism and root growth. However, as time passes these reserves are gradually consumed, at which point root growth ceases and root cells begin to starve from lack of carbohydrate (Salisbury& Ross, 1992; Taiz and Zeiger, 2002). Water and nutrient uptake is then affected and the tree starts to shed foliage, foliage becomes chlorotic and finally, and often quite suddenly, the tree wilts and the plant above the zone of ring-barking dies, which may result in the death of the whole plant.

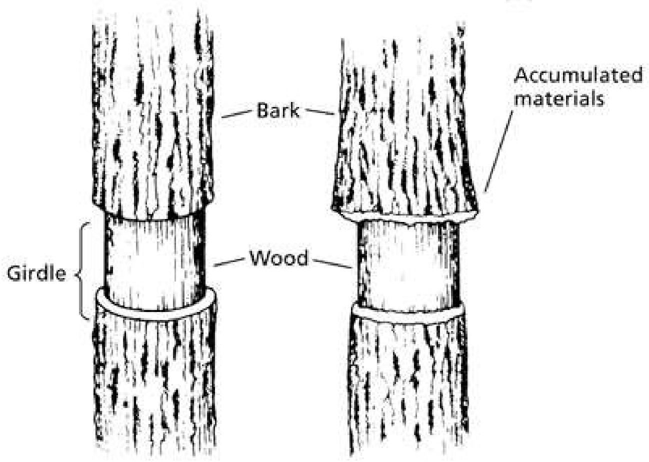


Figure 1. Swelling above the cut on a ring-barked stem (Taiz and Zeiger, 2002)

For a large tree with substantial carbohydrate reserves and a good root system, this process may take place over a period of between 2 to 5 years. However, if there are additional environmental stresses such as drought, flooding or waterlogging the decline of the tree will be accelerated.

Girdling affecting xylem and phloem tissues and transport

When girdling occurs, both translocation through phloem and transpiration through the xylem tissues are affected. However, the effect on transpiration is immediate as water supply to the trunk and canopy above the zone of girdling is cut and so on a warm windy day, wilting can begin almost immediately (McLuckie and McKee, 1954; Kramer & Kozlowski, 1960; Taiz and Zeiger, 2002). For most of the canopy and trunk above the girdling cut, permanent wilting will be reached within 24-48 hours depending on the size of the tree and environmental conditions. This girdling is a very effective method of killing plant tissues above the cut and the effects are almost immediate.

In contrast to transport through phloem tissue, transport of water and nutrients can be both symplastic and apoplastic (Figure 2). The latter is the movement of water and dissolved substances through the non-living cell walls and intercellular spaces of the plant. It is often forgotten that movement through the cell walls and intercellular spaces on a large tree can be quite significant and it is this movement and the properties of water, that go a long way to explaining why tissues immediately above cuts made in the trunk may not dry out or die. This may also explain why trees with major cuts though their trunks remain hydrated, healthy and growing.

It should also be noted that some species have anomalous secondary growth (Esau 1965). Such growth may result in some trees having alternating rings of cambia, xylem and phloem while others have lobes of xylem alternating with phloem. For some species from some dicotyledonous plant families, including *Myrtaceae*, phloem may occur inside as well as outside the xylem (Fahn, 1974). This intraxylary phloem may make it difficult to effectively ring-bark or girdle trees that exhibit this unusual structure and may explain why some juvenile trees which appear to be ring-barked or girdled remain unaffected.

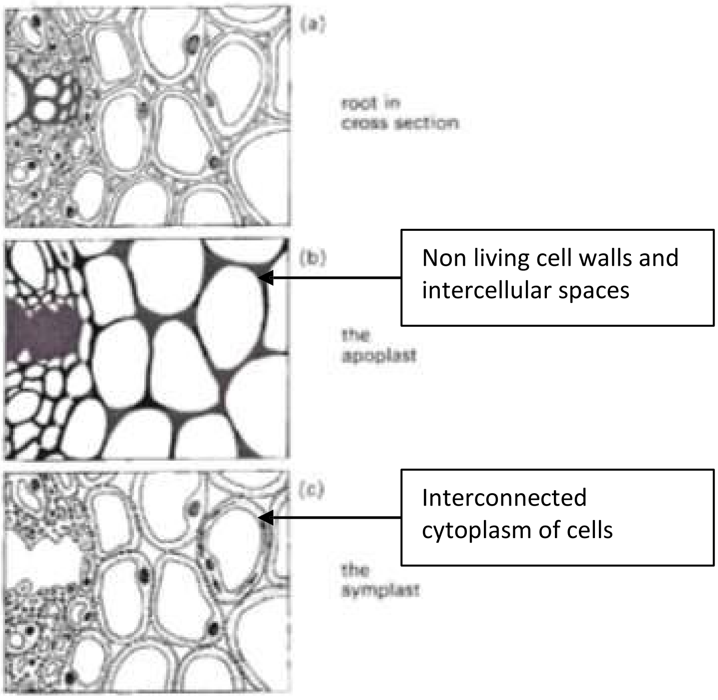


Figure 2. Symplastic and apoplastic pathways of plant transport (Salisbury and Ross, 1992)

The importance of the ring-barking and girdling cut and tree responses:

The physiological response of a tree is also influenced by the depth, width and location of the cuts made to affect the ring-barking and girdling (Figure 3). If the width of the cut made is quite narrow then the tree may be able to grow over the cut by producing callus, which can differentiate into woundwood within weeks to a few months (Neely, 1988; Goren et al, 2004). Trees are well-known to have simply grown over wire and other narrow obstructions, and ring-barking bands narrower than 100-150mm have been known to be grown over by large mature trees with substantial girths and carbohydrate reserves. Deliberate attempts to kill trees by ignorant or lazy vandals have also been thwarted when the cut narrow band (as narrow as 20-25mm) was simply grown over within a few months and the tree remained healthy and vigorous.

Figure 3. The width and depth of the cut affects the tree's response to ring-barking

Ring-barking and girdling are large wounds and the usual tree response is to produce callus from the cambium at the margins surrounding the damage. Callus production is greatest in vigorous trees but is affected by tree size, species and season (Neely, 1988). Spring, particularly early in the growing season, is typified by very fast responses to wounding and very rapid callus production, which can cover the damaged surface. Callus and woundwood that predominantly develops from xylem ray cells grow best when xylem tissue growth is most active (Harris et al, 2004).

If the tree has dormant buds, such as axillary or epicormic buds, below the cut made to ring-bark or girdle a tree, these may be stimulated to develop by the cessation of basipetal transport of auxins from the canopy. The auxins will be the primary hormone involved in the inhibition of these dormant buds. If these buds develop with sufficient speed and grow to be large enough, they may send photosynthate down to the root system which will continue to absorb and supply water and nutrients to the canopy. Similarly trees that have adventitious buds or roots may provide a system for circumventing the damage from ring-barking and girdling.

In these situations it is possible that the parts of the tree above and below the ring-barking cut may survive for very long periods of time and even many decades. Species that can produce adventitious roots, such as species propagated by layering, for example *Ficus* species or some river red gums, *E camaldulensis,* are capable of surviving for decades, and possibly centuries under such circumstances. However, the part above the cut usually eventually becomes stressed from environmental factors, such a drought or waterlogging, or the impact of insect grazing.

Another important aspect of ring-barking and girdling is the extent to which it occurs. There may be full or partial ring-barking and girdling of the trunk or major branches and stems. The effects of full ring-barking and girdling are clear, but a question arises as to how much of the vascular tissue needs to be intact for a tree to survive and recover over the longer term. Unfortunately there is little published information on this matter (Priestley, 2004) but it is known that there is variability in response for different species of trees, which is also influenced by season and environmental conditions (Neely, 1988).

Trees have certainly survived ring-barking and girdling to 50% of their trunk vascular tissues (Homes, 1984) and young trees of *Eucalyptus camaldulensis, Platanus orientalis* and *Acacia melanoxylon* survived and recovered from 60, 75, 90 and even 100% damage (Priestley 2004). Furthermore, foresters trying to kill weedy woody species, such as beech, poplar and some maple species by girdling have reported how difficult it can be (Glass, 2011; Kilroy and Windell, 1999). For the white poplar, *Populus alba*, which has the capacity to prolifically sucker, it has been reported that new bark can develop over the cuts in a matter of weeks (Glass, 2011).

The author's observations have been that as little as 10% vascular connection can be enough for trees to remain healthy, if the tree is growing in ideal situations and is kept free of pests and diseases (Moore, 2011). Deliberate attempts to kill the historic Separation Tree in the Royal Botanic Gardens Melbourne in 2010 by ring-barking or girdling reported that a band of bark between 400 and 900mm wide was removed from 80% of the circumference (Fagg, 2012; Moore, 2011). With 20% vascular connection, the tree remains in full foliage, healthy and both callus and woundwood have been produced expanding the vascular connection. The woundwood differentiates into xylem and phloem tissues and new vascular cambium is also developed (Harris et al, 2004).

Other effects of Ring-barking and Girdling

One of the reported consequences of ring-barking has been an increase in fruiting and flowering, which is often attributed to the retention of and higher levels of carbohydrate in the canopy of the tree (Kramer and Kozlowski, 1960), as well as a survival response at times of extreme stress (Taiz and Zeiger, 2002). This response is the basis of the use of horticultural girdling and ring-barking, which usually leaves between 10-20% of the vascular connection intact (Goren et al, 2004). However, there are little, if any data published on plant longevity after ring-barking or girdling.

In research on the effects of ring-barking and girdling young trees of *Eucalyptus camaldulensis* and*Platanus orientalis* trees were girdled and *Acacia melanoxylon,* trees were ring-barked for 60, 75, 90 and 100% of their girth (Priestley, 2004) using the definitions of ring-barking and girdling presented earlier. While the depths of cut were different, the results were not as there were no apparent differences between trees in their responses regardless of whether they had been ring-barked or girdled.

Interestingly, whole tree or above cut deaths only occurred in the 100% treatment. All specimens survived even 90% ring-barking or girdling, probably because the experiment was conducted over a 13 week period which was not long enough for plants to die and because the trees were juvenile and vigorous, they simply grew over the cuts that were made to the trunks. Callus tissue is produced by repeated divisions of the most recent derivatives from the cambium with the majority of callus (parenchyma) cells originating from cells destined to form xylem rays (Neely, 1988). Young trees would contain a lot of such tissue. However, a number of interesting other effects emerged (Priestley, 2004):

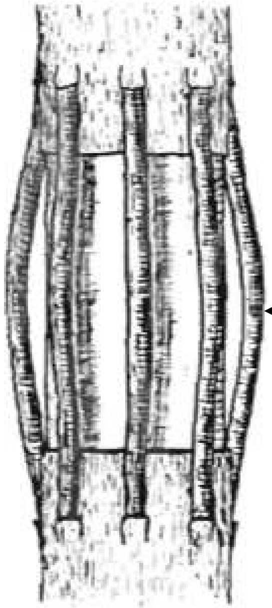
- For *P. orientalis*, the more severe the treatment the slower the bud burst in spring and the less dense the canopy that subsequently developed (a greater response as you go from 60-100%). Later in the season the numbers of fruits produced by the 90 and 100% treatments were significantly lower averaging 6.25 and 4.00 per tree respectively compared to 14.25 for untreated controls.
- For *P. orientalis*, the more severe the treatment the greater the number of branches that were shed from these young tree (again, a greater response as you go from 60-100%).
- For *E camaldulensis*, the undamaged controls showed an average increase in height of about 62mm, while none of the girdled treatments average over 30mm and most were considerably less.
- For *E camaldulensis*, the level of Psyllid infection at the end of the experiment was between 60 and 90% for ring-barked specimens compared with an infection rate of 12.5% in undamaged controls.
- For *A melanoxylon*, there was an effect for infection with leaf blight but in the reverse direction. The blight affected control plants but was much reduced for the most severely ring-barked treatments.

What these data reveal is that even incomplete ring-barking or girdling can affect the growth and development of injured trees as well as their responses to pest and diseases.

Arboricultural treatments for Ring-barking and Girdling

A number of arboricultural treatments for ring-barking and girdling have been suggested, including:

- When bark is removed from a tree accidently or by vandalism, the bark should be replaced in position immediately as natural grafting and callus growth can take place so that growing over occurs very quickly. This process can be described as bark patch grafting. The key to success is speed, as the bark that has been detached cannot be allowed to dry out nor can the damaged edges of the bark remaining on the tree dry. The work of Chandler (2009) showed that keeping eucalypt woody tissues moist facilitated successful callus growth and grafting success in *Eucalyptus leucoxylon*. Care must also be taken to replace the bark at the right orientation so that, for example, the part facing upward remains in that orientation and that there is as much contact as possible between the replaced patches of bark and the bark on the tree (McGarry, 2001). The bark can be held in place by any biodegradable material, but any fastening will suffice given the size and seriousness of the wound. Success may also be affected for some species by season, with better rates of patch grafts occurring in spring and autumn for eucalypts than in winter or mid-summer (McGarry, 2001).
- Bridge grafting is a well-known horticultural technique that has a long history of use in repairing damaged orchard trees (Hartmann and Kester, 1975; Harris et al., 2004) but it has also been used to repair damaged ornamental trees of historic, heritage, cultural, landscape and horticulture significance which warrant the expenditure. The technique uses bark tissue from the same specimen, a clone, or the same species, which is inserted into the remaining healthy bark of a ring-barked or girdled tree. The objective of bridge grafting, as the name suggests, is to provide channels of connection of both xylem and phloem tissue that allow transport basipetally and acropetally once more (Figure 4). Success relies on healthy cambium producing callus at both ends of the grafted bark and the rate of success can be influences by species and seasonal factors. Bridge grafting requires skill and is quite expensive to undertake and so it is usually only contemplated for outstanding and significant trees. On a large tree, a number of grafts, up to 10 or more may be inserted, and the aesthetics of the outcome are sometimes questioned by arborists and the general public.



A number of slots are created in the healthy bark and the scion wedges are inserted into flaps of bark at each end. Care must be taken to orient the scions correctly, and they may bow out slightly. They can be fixed in position with tape or adhesive.

Figure 4. Bridge grafting of a ring-barked trunk (modified from Hartmann and Kester, 1975)

- Approach grafting and inarching are other well-known horticultural techniques used in repairing damaged orchard and valuable ornamental trees (Hartmann and Kester, 1975; Harris et al., 2004). They differ in that for inarching, the top of the new rootstock plant does not extend above the point of the graft union. Inarching is considered to be a form of 'repair grafting'. Both techniques involve growing young seedlings that are progeny of the damaged plant, clones or at least of the same species as the damaged plant around the base of the damaged tree. The young trees should be of a reasonable size (1-2m in height with a stem diameter of 20-25mm if possible) and the trunk or one of the larger branches is then inserted into the healthy cambium of the damaged tree above the upper cut of the ring-barked or girdled region. The objective of approach grafting is to provide water and nutrients to the part of the damage tree above the zone of ring-barking or girdling, but it does not provide for transport downwards to the original root system. However, if successful and given enough time the young tree root systems develop as the original system declines and in some cases natural root grafting between tree and seedling may occur (Tarroux and DesRochers, 2011). This technique is relevant when water is likely to be a limiting factor in the survival of a damaged tree and there is a significant risk of imminent wilting. Once more, approach grafting requires skill and is quite expensive to undertake. On a large tree a number of grafts, up to 6-8, or more grafts may be inserted, and the aesthetics of the outcome are sometimes questioned as there are a number of smaller trees growing around the trunk of the specimen.
- Another aspect of post-damage management that an arborist can undertake is to minimize the risks from environmental stresses. For the most part this will involve making sure that water and nutrients are not limiting and that there is no risk of waterlogging to the already stressed root system. Good subsurface irrigation and drainage and proper mulching around the drip line would be useful practices. Post-damage control of pests and diseases is also wise (Priestley, 2004). Even partial ring-barking and girdling of trunks or larger branches exposes plants to significant stress which may leave them vulnerable to pest and disease attack. For example, the attack on *E camauldensis* by the psyllid, white lace lerp (*Cardiaspina albitextura)* was confined to trees that had been ring-barked or girdled and not to undamaged control trees that were largely unaffected (Priestley, 2004). Psyllids are attracted to high nutrient levels in foliage and population numbers increase rapidly in these conditions (Collett, 2001) which is consistent with ring-barking and girdling causing an increase in sugar and carbohydrate accumulation above the zone of damage (Kramer & Kozlowski, 1960). It is possible that these conditions might also suit some fungal pathogens.
- Injections of sucrose into the soil have been reported to significantly improve fine root growth of established trees with responses dependent on species and the sugar concentrations applied (Percival et al, 2004). It is unclear whether the response is due to the direct uptake of the sugar by

the roots or to enhanced mycorrhizal growth, which would also benefit the tree. The timing of such applications is also critical. It should not be too early after damage as the roots, under normal circumstances, should have sufficient carbohydrate reserves, but could be applied when carbohydrate resources are in danger of depletion. Measurement of carbohydrate concentration in root tissue could inform the timing of application. Care must also be undertaken to ensure that the injected sugar does not benefit non-target organisms.

Conclusion

Depending on the tree and the conditions that it is growing under, ring-barking may not mean the death of a tree, but little can be done if a tree is effectively girdled severing the active xylem tissue. Arboricultural treatments that respond rapidly (within hours) to the removal of bark and which provide ideal growing conditions for the tree enhance the chances of recovery from ring-barking. Treatments may involve irrigation, mulching, prevention of compaction and waterlogging and effective pest and disease control.

Depending on the species, environmental conditions and the time of year, re-affixing displaced bark (bark or patch grafting) can be successful if it is done within hours of removal and the tissues, both intact and displaced, have not dried out. If successful, callus production can be very rapid and growing over can occur within months. If the tissues dry or cannot be replaced other interventions such as bridge or approach grafting may be contemplated, but they can affect the aesthetic value of the specimen.

It should also be understood that healthy vigorous trees that appear to have been fully ring-barked or girdled, on closer and detailed inspection may prove to have only been partially girdled or ring-barked. Such trees may survive with as little as 10-20% vascular connection or less if they are young and healthy. Under these circumstances, the “do nothing to the tree” option may be an appropriate response provided that good arboricultural management practices are implemented subsequent to the injury.

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