24th NATIONAL STREET TREE SYMPOSIUM
7 & 8 SEPTEMBER 2023

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## CONTENTS

TREENET MEMBERS 2023 .................................................................................................................................................. 3
DONORS 2023 .............................................................................................................................................................. 5
TREENET MANAGEMENT COMMITTEE 2023 ................................................................................................................ 6
TREENET ADVISORY BOARD 2023 ............................................................................................................................ 6
NATURAL ASSETS IN INFRASTRUCTURE PROJECTS ............................................................................................... 7
  DAVID JENKINS ..................................................................................................................................................... 7
MILLENNIUM KIDS: YOUTH LEADING CHANGE ........................................................................................................ 15
  CATRINA LUZ ANIERE ........................................................................................................................................... 15
URBAN TREE SPECIES SELECTION FOR FUTURE CLIMATES – MORE DIFFICULT THAN YOU THINK ............ 24
  STEFAN K ARNDT, STEPHEN J LIVESLEY, PATRICIA R TORQUATO, CHRISTOPHER SZOTA ...................................... 24
THE DEMANDS WE PLACE ON STREET TREES: A CASE STUDY OF EUCALYPTUS LEUCOXYLON F.MUELL ....... 32
  G. M. MOORE AND A. CHANDLER ....................................................................................................................... 32
ENGINEERED SPACES FOR TREES IN DUBBO REGIONAL COUNCIL – MODIFIED STOCKHOLM TREE PLANTING
  METHOD ............................................................................................................................................................. 43
  IAN MCALISTER .................................................................................................................................................. 43
ENGINEERED SPACE FOR TREES IN MOUNT BARKER DISTRICT COUNCIL .......................................................... 54
  SHRADDHA DHUNGEL, CHRIS LAWRY, TIM JOHNSON ......................................................................................... 54
ENGINEERING FOR TREES ........................................................................................................................................ 73
  RUSSELL KING AND TIM JOHNSON ....................................................................................................................... 73
THE ART OF TREE PHOTOGRAPHY ......................................................................................................................... 91
  GRAHAM GALL .................................................................................................................................................... 91
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<th>Fleurieu Peninsula Family History Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Citygreen</td>
<td>Verve</td>
</tr>
<tr>
<td>Dr Greg Moore</td>
<td>Kate Denton</td>
</tr>
<tr>
<td>Ezy Badges</td>
<td>Michael Gregg</td>
</tr>
<tr>
<td>Space Down Under</td>
<td>Ven Grollmus</td>
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<td></td>
</tr>
<tr>
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</tbody>
</table>
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Abstract
In the drive for financial and environmental sustainability natural assets can be used in parallel with or to replace some traditional approaches and hard assets. An infrastructure project to reduce risk of flooding that may, for example, have previously used hard assets like a dam or a levee built from materials trucked into the site might instead use vegetated wetlands. In many cases these natural solutions come with lower capital and operating costs and they can mitigate urban heat islands and support resilience to the impacts of climate change. Natural assets also bring additional benefits, they can enhance recreational opportunities, purify air, improve soil quality and enhance habitat. Collectively the interaction of urban green infrastructure components can help to conserve biodiversity and restore ecological processes. Canada and in particular the state of British Columbia have become leaders in this emerging area of asset management practice. This paper reviews some leading examples of the application of natural assets in urban green infrastructure.

Introduction
The Institute of Public Works Engineering Australasia (IPWEA) is the peak association for public works professionals across Australia and New Zealand. IPWEA was established to enhance the quality of life for communities via continuous improvement and best practice in all aspects of public works, services, infrastructure planning, delivery and operations. IPWEA provides services to members and advocates on their behalf. Our core business is to provide tools and resources to support all asset intensive organisations manage their assets and for local government to maintain the high level of service the community demands.

We are aware that as the human population grows beyond 8 billion our consumption of natural resources continues to grow exponentially. The World Bank estimates that infrastructure now accounts for approximately 70% of global greenhouse gas emissions and half of all resources used and waste created globally. Add to that the projection that 60%-70% of the 2050 infrastructure is not yet built, and it becomes obvious that the infrastructure sector has enormous potential to reduce the impacts of climate change and demand on water and other raw materials.

One approach to reducing infrastructure resource inputs is to include nature-based solutions such as natural assets and green infrastructure to support or in some cases replace hard infrastructure. The benefits of green infrastructure (GI) and the ecosystem services it can provide are extensive and include stormwater runoff reduction and treatment, air and water quality improvement, mitigation of urban heat island effects, reduction of energy consumption in buildings, sequestration and storage of carbon, protection of wildlife habitat and improvement in human health and well-being (Green Infrastructure Network, 2023; US EPA, 2021). A range of GI assets and the value, benefits and services provided, the threats and challenges natural and green infrastructure must address, and how we might include green infrastructure in traditional infrastructure approaches are considered in this paper and presentation through examination of some case study examples.

Traditional infrastructure assets and their management
The ISO 55000 standard defines an asset as “something that has potential or actual value to an organization”. Traditional infrastructure assets are physical assets that contribute to meeting the needs of major economic and social facilities and services. They are typically large, interconnected networks or portfolios of composite assets and include a variety of classes including road and road related assets (road pavements, road surfaces, bridges, culverts, footpaths, kerb and channel/gutter, stormwater drainage systems (pipes, open channels, pits, inlet structures, stormwater treatment and water sensitive urban design systems) recreation facilities (passive parks, active sports fields), buildings, (public, community and sporting buildings), water supply and sewerage assets.
Assets are managed at the component level. A component is part of an item of property, plant or equipment that has a significant cost in relation to the total cost of the asset. It has an independent physical or functional identity and specific attributes such as different life expectancy, maintenance regimes, risk or criticality. The components of assets may be separately maintained, renewed or replaced individually so that the required level and standard of service from the network of assets is continuously sustained. Generally, the components and hence the assets have long lives and need to be managed throughout the asset life cycle from planning and design through acquisition and deployment, operation and maintenance, and finally decommissioning and disposal / recycle.

Infrastructure asset management is the systematic process of managing an asset through each of its life cycle stages. A range of measures are considered in infrastructure asset management, including: cost; risks; efficiency; durability; safety; customer satisfaction; quality; capacity; reliability; responsiveness; environmental acceptability; availability; functionality; sustainability and other performance attributes (ISO 55000:2014). In most jurisdictions there are legal and financial requirements that must be met in the management of infrastructure assets.

**Natural and green infrastructure assets**

Natural assets, green infrastructure or urban green infrastructure are terms that refer to natural resources or ecosystems that are intentionally managed to provide multiple benefits for the environment and for human well-being. They can be applied at different scales, from individual buildings to entire landscapes, and can include various forms.

Green infrastructure (GI) includes natural assets (such as air, water, soil and both natural and restored ecosystems such as wetlands, forests, lakes, rivers, mangroves, coastal dunes, living shorelines, meadows and pastures) as well as hybrid or enhanced assets that combine engineered and nature-based elements. These include urban forests, bioswales, storm water ponds, parks and gardens, street trees, rain gardens, roadside verges, vegetable patches, bikeways and pedestrian trails, green roofs or walls, rain gardens, cemeteries and community gardens (Figure 1).

![Green Infrastructure](image)

*Figure 1: Green infrastructure examples (Source: MNAI, 2023).*

The inclusion of GI in urban landscapes is usually intended to enhance the quality of life of citizens, to improve resilience, or to conserve, restore and support natural ecosystems and biodiversity which provides ecosystem services (Jun Ying et al., 2022). Globally, ecosystem services from GI have been estimated using a range of
methods such as market prices, revealed preferences, or stated preferences, to provide benefits of US $125-140 trillion per year - more than 1.5 times the size of global GDP (Nature4Climate, 2023). However, these benefits are often undervalued or ignored in conventional economic accounting and decision making, leading to the degradation and loss of natural capital and biodiversity. Natural or green infrastructure assets have not traditionally been included in asset managers’ portfolios.

**Value and benefits of green infrastructure assets**

To provide community services cost-effectively and sustainably now and in the future, governments continually seek ways to improve the management of their critical assets that supply essential services. GI assets have the potential to provide a range of services of benefit to humans. Emerging evidence shows that identifying, measuring and managing natural assets, and creating green infrastructure as part of an overall asset management strategy can save capital and operating costs and reduce risk when compared to engineered alternatives. In addition, natural assets can be long-lived or perpetually self-regenerating and are often more resilient and adaptable to climate change (MNIA, 2023). Additional benefits of GI include the provision of clean air, food and water, enhanced pollination, reduced pollution, stormwater management, carbon sequestration, noise reduction, biodiversity conservation, improved human health and well-being, recreational and economic opportunities, and strengthened cultural and aesthetic values.

Street trees, parks and urban forests can: reduce air pollution by filtering particulate matter and absorbing gaseous pollutants such as nitrogen dioxide and ozone, lower ambient temperatures and the urban heat island effect by providing shade and evaporative cooling, reduce building heating and cooling costs and energy consumption, improve human health by reducing respiratory disease, increase property values, provide a sense of scale within the built environment, and offer ecosystem benefits. Natural and green assets can improve resilience against extreme weather events and climate change impacts by reducing greenhouse gas emissions, enhancing carbon sequestration, lowering urban temperatures, increasing water retention and infiltration, and reducing sea level rise.

Coastal assets such as mangroves, dune systems and artificial reefs can reduce coastal flooding and erosion, sequester carbon, support fisheries and tourism, provide habitat for many species, provide tourism and recreation opportunities and reduce the impacts of sea level rise. It is estimated that if today’s mangroves were lost, 18 million more people would be flooded every year (a 39% increase) and annual damages to property would increase by 16% (US $82 billion).

Urban green spaces and wetlands can enhance water retention and infiltration, reducing surface runoff and flooding. They can also improve water quality by filtering pollutants and nutrients from storm water before returning it to rivers and underground aquifers prior to reuse. Natural and green infrastructure can also provide habitats and corridors for various species of plants and animals, increase urban biodiversity and enhance ecological resilience. GI can increase opportunities for physical activity, social interaction, relaxation and the enjoyment of nature – all of which improve human mental health and well-being by reducing stress, enhancing mood and cognitive function. From an asset management perspective green infrastructure can also come with lower capital and operating costs, and generate economic value by increasing property values, rental rates, sales revenues, employee retention, and customer satisfaction. (This summary of benefits was compiled from MNIA (2018); Moore (2000); Bolund & Hunhammar (1999); Ma, Henneberry, Privitera, & Mastrucci (2021); Donovan & Butry (2010); Jim & Chen (2006); Tyrväinen, Mäkinen, & Schipperijn (2007); Nature4Climate (2023)).

**Threats and challenges for green infrastructure assets**

Despite their value and benefits, GI assets face several threats and challenges that have the potential to undermine their provision and diminish the quality of ecosystem services delivered. These include lack of recognition, valuation and financing, degradation and loss of natural habitats, competing land uses and development pressures, and insufficient data and knowledge regarding their safety, performance, benefits, maintenance, operation and management. More specifically GI assets face the following threats and challenges.
Education, expertise and knowledge:
- lack of awareness and knowledge of the multiple benefits and values of GI among policy makers, practitioners, and the public
- loss of expertise from local government and lack of horticultural input to decision making
- lack of data and tools for the valuation of ecosystem services and disservices, life span, performance, benefits, costs
- lack of capacity and skills to implement and manage green infrastructure effectively and efficiently
- inadequate data and evidence to support design and evaluation of GI interventions

Policy and finance:
- poor coordination and integration among different sectors and stakeholders involved in GI planning and management
- failure of legal and institutional frameworks to incentivize, support and regulate the use of GI
- lack of understanding of GI ecosystem service interactions, e.g. increasing tree cover at the cost of reduced solar radiation
- insufficient funding and financing mechanisms to support the development and maintenance of GI.

Hard infrastructure developments:
- loss of public and private open space
- inner city re-development and urban sprawl that reduce the availability and connectivity of green space, affecting their ecological functions and services
- overhead cables; communications and power distribution company policies and poor practices for power line clearing
- underground infrastructure including cables, plumbing and drainage
- competing demands between GI and other land uses or interests creating conflicts over the allocation and management of green spaces (e.g. development Vs green space and trees).

Environmental threats:
- unmanaged pests and diseases
- the changing climate
- exposure to various sources of pollution and disturbance that can degrade the quality and health of green spaces and their biotic components, e.g. air pollution can damage vegetation and reduce photosynthesis, herbicide use, chemical fertilizers
- thresholds or tipping points beyond which irreversible or undesirable changes may occur, e.g. biodiversity loss or climate change may reduce ecosystem resilience and stability and compromise ecosystem services


Asset management for green infrastructure
Harnessing GI assets in the service of urban areas is an innovative and promising concept that can enhance the liveability and sustainability of cities. With effective monitoring, maintenance and rehabilitation, natural and green assets can provide service and add value for decades in ways that many engineered assets cannot match. However, GI requires careful planning, monitoring and evaluation to ensure that it delivers the desired outcomes for different stakeholders. The management of green infrastructure requires a cross-disciplinary approach that involves policy makers, planners, designers, engineers, researchers, horticulturists and potentially ecologists and hydrologists. It also requires a clear understanding of the multiple advantages and challenges of green...
infrastructure and the threats posed by rapid environmental and social change in urban environments and in the changing climate.

As with traditional assets, managing GI assets requires a systematic process of planning, operating, maintaining and upgrading green infrastructure to deliver its environmental, social and economic benefits and services. GI assets require regular monitoring and maintenance to ensure their optimal performance and longevity. Incorporating GI assets into traditional asset management systems requires that the GI components be properly valued and managed.

Initial steps require GI assets to be integrated into established asset management policy and practise via high level strategic planning. Next, an inventory of key GI assets must be compiled, including the services they provide. An assessment of asset value and condition can then be undertaken to compare service provision against engineered options. Doing this requires comprehensive information in an asset management system for each component (specimen, swale, length of stream) and / or asset (forest, wetland, dune system) including its identity, location, age, condition, value and management (maintenance and renewal) schedule. A corresponding financial management plan is also required to ensure funding for the assets and understanding of return on investment. Asset management for GI can be implemented within an organization by:

- communicating and engaging with stakeholders on the benefits of their GI assets
- identifying the current state and value of their GI assets
- assessing risks and opportunities associated with their GI assets
- prioritizing and allocating resources for their GI assets
- tracking and reporting on the performance and impact of their GI assets

Green infrastructure has the potential to provide a win-win solution to achieving sustainability goals and improving human health, well-being, and environmental quality. However, overcoming the challenges and bringing about wider adoption of GI assets into asset management will require:

- improved acceptance of GI as a mainstream alternative or addition to hard assets
- cross-sectoral partnerships and stakeholder engagement in GI decision-making processes
- increased biodiversity within GI projects
- development of robust methods for valuing GI benefits and costs across different spatial and temporal scales and improved economic valuations for GI
- optimised spatial configuration and composition of GI for multiple benefits
- identification and development of metrics, models and tools for the planning and assessment of GI
- turning research into policy and implementation

Several frameworks and guidelines have been developed or are under development to assist with the mainstream expansion of GI:

- International Capital Market Association Green Bond Principles and Sustainability Bond Guidelines, which provide standards for issuing bonds to finance GI projects (ICMA, 2023)
- HSBC Global Asset Management Green Impact Investment Guidelines, which outline eligible green activities and impact reporting expectations for bond investors (HSBC, 2020)
- US Environmental Protection Agency (EPA) Stormwater Asset Management Framework, which helps municipalities plan, track and manage their stormwater GI projects (EPA, 2022)
- CIRIA Asset Management of Blue Green Infrastructure Guiding Principles Project, which is developing best practices for managing BGI assets that combine water and vegetation features (CIRIA, 2023)
- The Green Infrastructure Ontario Asset Management Framework is currently developing a roadmap for developing an asset management plan for GI in Ontario and includes a suite of resources and reports (GIO, 2021)

In Canada, the Natural Assets Initiative (NAI) is now providing scientific, economic and municipal expertise to support and guide local governments in identifying, valuing and accounting for natural assets in their financial
planning and asset management programs and developing leading-edge, sustainable and climate-resilient infrastructure. They have been able to develop resilient, long-term infrastructure alternatives at substantial savings and to incorporate this information into mainstream asset management systems (MNAI 2023).

Case study examples

Case studies from different regions of the world illustrate the potential of green infrastructure projects to deliver multiple ecosystem services and co-benefits for urban communities. Examples include:

- In the Netherlands the Hondsbossche Dunes infrastructure project replaced a conventional dike with a soft coastal barrier made of sand. The dunes have improved the safety and security of the area but also created new recreational and ecological opportunities.

- In Indonesia, the World Bank is supporting the government’s ambitious target of rehabilitating 600,000 hectares of mangroves by 2024. The project leverages the power of communities to collect national data on mangroves, provides incentives for mangrove protection and restoration, and promotes sustainable livelihoods and blue carbon markets.

- In India the East Kolkata Wetland Complex project is a natural sewage treatment system that covers 3,000 hectares on the edge of Kolkata. It removes phosphorus from wastewater and provides a resource for fish farming and agriculture.

- The City of Adelaide, Australia created a streetscape of vegetated rain gardens within road reserves to capture and filter pollutants and sediments from stormwater runoff. The rain gardens also provide aesthetic benefits, traffic calming effects and habitat for native plants and animals.

- In Comox, Canada the restoration of Brooklyn Creek enhanced its ability to improve water flow as well as spread, retain and infiltrate water to reduce flooding. The restored creek improved fish habitats, portions of urban woodlands and natural areas to enhanced parks and trails.

- The Korea Superconducting Tokamak Advanced Research (KSTAR) facility (Korea Institute of Fusion Energy) has installed a green roof that covers 12,000 square meters and reduces stormwater runoff by 60%.

- The city of Portland, Oregon, has implemented a Green Streets program that uses rain gardens, bioswales and permeable pavements to capture and filter stormwater runoff from streets and sidewalks.

- The city of Singapore has developed a comprehensive greening strategy that aims to increase the urban tree cover from 36% to 50% by 2030 and create a City in a Garden.

- The city of Curitiba, Brazil, has transformed an abandoned quarry into a botanical garden that hosts a variety of native plants and animals and attracts millions of visitors every year.

- In Detroit, Michigan, USA, a former elementary school site was transformed into a four-acre urban farm called Food Field. The farm produces fruits, vegetables, eggs, honey and mushrooms for local markets and restaurants. It also features a solar-powered aquaponics system, greenhouse and composting facility. The farm provides employment opportunities, community engagement, education and green space.

- In Sri Lanka, a project supported by the Food and Agriculture Organization (FAO) integrated urban agriculture and forestry into climate change action plans of six municipalities via the establishment of home gardens, community gardens, rooftop gardens and school gardens to enhance food security, income generation, waste management and disaster risk reduction. It also supported the planting of trees along roadsides, riverbanks and public spaces to improve urban microclimate, air quality and biodiversity.

- In Beijing, China, an eco-corridor was designed to connect the Olympic Forest Park with the surrounding urban fabric. The corridor consists of a series of green spaces that provide habitat for wildlife, recreation for residents and visitors, stormwater management and climate regulation. The corridor also showcases different types of native vegetation and landscape features that reflect the local culture and history.

- In Lugo, Spain, a set of urban forestry and agriculture actions were implemented within the EU LIFE Program to reduce CO2 emissions and enhance resilience. The actions included planting trees along...
streets and public spaces, creating urban orchards and gardens, restoring riparian forests along rivers and streams, and promoting agroforestry practices in peri-urban areas. The actions resulted in increased carbon sequestration, improved water quality and quantity, enhanced biodiversity and social capital.

Conclusion
There is a growing urgency to improve sustainability, reduce demand for natural resources, reduce greenhouse gas emissions and adapt to climate change. As a sector, infrastructure is responsible for 70% of global greenhouse gas emissions and half of all resources used and waste generated. As a result, we have a huge responsibility and opportunity to respond to these challenges in a sustainable way. Embracing nature based solutions such as green infrastructure and natural assets has the capacity to provide a wealth of win-win solutions and provide climate resilient ecosystem services for our urban environments and habitat for biodiverse plant and animal communities.

The benefits of green infrastructure are significant and include stormwater reduction and treatment, air and water quality improvement, mitigation of urban heat island effects, reduction of energy consumption in buildings, storing of carbon, protection of wildlife habitat and improvement in human health and well-being. To capitalise on these benefits we need to communicate them to stakeholders and then embed green infrastructure into asset management systems and processes. This process will ensure that the necessary values, priorities, resources and funds are put in place to mainstream nature-based solutions at a global scale. There is much work currently underway in this space, a number of guidelines have been developed and more are in progress. IPWEA looks forward to playing a part in our resilient and sustainable future.

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MILLENNIUM KIDS: YOUTH LEADING CHANGE
Catrina Luz Aniere
Millennium Kids Inc.

Abstract
In the early 1990’s a teacher mused that environmental education would one day have the highest priority. Over several years she’d led students to adopt landscapes and working with other teachers had embedded environmental education in cross-curriculum processes. In 1995 her students attended the first United Nations Environment Program Children’s Environmental Conference where the rights of youth to have a say about their world was highlighted. This conference was the catalyst that brought together in Western Australia a team of young people and adults to support youth to make a difference. In 1999 Millennium Kids Inc. began and young people have been voicing their concerns, pitching ideas, making change and caring for their local environment since. Processes developed by Millennium Kids focus on hearing youth and facilitating meaningful opportunities for them to take local action to implement their ideas. By highlighting Millennium Kids’ learnings this paper aims to inspire thought on how young people might be included in other stakeholder engagement models – they are the changemakers who will inherit the planet, after all.

Introduction
Millennium Kids acknowledges Aboriginal and Torres Strait Islander Peoples as the Traditional Custodians of Australia and recognises their ongoing role, responsibilities and continuing connection to land, waters, culture and knowledges. Millennium Kids acknowledges the Traditional Custodians of the land where we operate and respects its Elders past and present and as living leaderships.

Founded in Western Australia in 1999, Millennium Kids is a not-for-profit environmental youth organisation that is grounded in the rights of the child to have a say about their world and their future. Preparing this paper prompted reflection and provided an opportunity to ponder how Millennium Kids may have or may not have influenced the environmental education agenda across Australia and beyond, and to consider where to from here? This paper highlights learnings from Millennium Kids over nearly 30 years. It is hoped this will inspire others to apply and build upon Millennium Kids’ findings and to avoid some pitfalls. It is not just about letting youth have a voice, it is also about engaging young people more and in more meaningful ways in supported youth-led action, because we need the young people who will inherit the planet to be the changemakers now.

Tsundoko. My journey.
Many books are bought only to let them pile up on the shelf. Statistician Nassim Nicholas Taleb believes surrounding ourselves with unread books, ‘tsundoko’, enriches our lives as they remind us of how much we don’t know. This word reinforces that we are on a journey, we never stop learning, we keep adding to our knowledge and refining our view of the world and how it works. This is childlike behaviour; it is what kids do naturally and subconsciously. Children don’t get bogged down like adults around them frequently do when defending an indefensible position. Children keep asking the big questions.

My name is Catrina Luz Aniere. My father told me Aniere means sword fighter. It’s a pity that we can now google Aniere and discover it means donkey cart driver! As a child I liked the sword fighter story, fighting against injustice, but as years passed I began to appreciate the characteristics of a donkey: intelligent, stubborn, logical, but with a flexible approach to problem solving - and the image of the cart driver getting the job done. I was born in England of an Australian mother. My father’s family fled the Basque region for England during the Spanish civil war, then migrated to Whadjuk country, just outside Perth, in 1962. Pondering one’s origin can be important when discussing views, particularly on environmental education and planet care; it also helps sum up attitudes to Country: change and adapt.

My Basque father opted for a farm life and my early memories are of dairy cows and water conservation, of tapping the water tank to see where the level was, and sharing bath water. Free play in the bush, bare feet in winter creeks, catching tadpoles and glies, talking to birds, and solace amongst trees. Conversations were had
about not levelling the bush block at the front of the farm and about neighbours protecting river areas. Not many, but enough for my young ears to understand that bush had value.

Those early experiences informed my journey as an environmental educator, which has always been embedded in action learning or student-centred learning. Kids outside, experiencing nature, doing science, writing stories and poetry, asking questions. Celebrating awe and wonder. I had planted my first trees in salt prone gullies and questioned the clearing of farming areas before graduating as a primary school teacher in the 1980s and heading thousands of kilometres north to the Pilbara.

While working in the north an Indigenous teacher invited me to travel with his uncle, an Elder, on Country in the vast Kimberley region. On the road trip the Elder asked me a simple question: *What is your job?* I replied *‘I teach children how to read’,* to which he responded *‘then I will teach you how to read the land.’* This was a pivotal moment, one of deep reflection, on the beginnings of understanding another language and other ways of seeing and doing.

In the Pilbara we began supporting five-year-old students to ask the big questions and then to seek the answers. When a tap was left running we asked “where does our water come from?”. To find the answer we followed the water pipe, literally, from the classroom to the water tower in town a 10 kilometre long bus ride away. *But how did the water get to the tower?* To answer this a local high school teacher drove the bus to the De Grey River 80 kilometres away, where we lay on the ground to hear the water being pumped. We discovered the Port Hedland Water Supply. The kids made the connections. They learnt through action and gave meaning and reason to the sign above the tap: “water is precious”.

On returning to a school in the city in 1991 the Swan River was close by. It made sense to make the river a classroom as it was so close, as was Perth Zoo. The river was a perfect site for an outdoor classroom. Unfortunately, a freeway straddled and fragmented a migratory bird feeding area on the mud flats along the river’s edge and restricted the community’s access to the water. With the aid of an overpass it still provided good opportunities to engage the students in nature. Building on Pilbara experience we developed action-learning programs based on the student’s questions. These let the kids explore, ask more questions, develop projects, foster partnerships and make community connections. Where do the birds come from? Where have the plants gone? Why did they put the freeway here? Can the freeway be put underground?

A whole-of-school project was developed in collaboration with Perth Zoo, local and state government, and with the community. Teachers were on board. Artists in Residence produced murals of migratory birds. Raps were written in music class. Trees were planted. Even the bike safety teacher worked out a way to build the program into the curriculum. The local council recognised the value of this work and asked if it could be scaled up to include all schools in their area – the Bushland Project had begun.

Teachers elsewhere in the state were concerned about the lack of environmental education in the curriculum at that time. Science, English, geography and primary school teachers more generally gave voice to the need for Department of Education support. A group of teachers formed *Green Teach* which drove an agenda of change, ran professional learning workshops and brought bright minds together to exchange ideas. Environmental education was woven into the curriculum and frameworks were developed for how it could be cross-curricular. We shared learnings, advocated for change and met with ministers to seek support. These groups were pivotal in framing a vision for teachers with agency.

Grounded in early childhood education philosophy we challenged the status quo and got the students outdoors. As our professional agency was being questioned and diminished by a rigid curriculum a multitude of questions were forming. How do we hold onto our agency and best give agency to the young people in our care? How do we embrace new thinking, keep learning, challenge ourselves to review and evaluate our processes and our thinking, to do things better? How do we best engage with young people so they become thinking, active custodians now and in the future? There were highs and there were lows.
The lows:

- We approached the Minister for Education with the idea that every piece of school bushland was a living, breathing museum, an educational place that needed to be preserved for future generations, where children could learn life sciences based in reality in real time. We didn't get a second meeting.
- Good teachers who loved their roles left, exhausted by administrivia and unrealistic reporting procedures.

The highs:

- Scaling environmental education across the local government area and supporting teachers and students at this scale
- The school-based Bushland Project won a Greening Australia Award in 1993.
- Student leaders from the school Bushland Project were invited to join the first United Nations Environment Program Leave It To Us Children’s Environment Conference in the UK in 1995. On their return they wanted to hold their own conference in WA, a conference for kids that was led by kids.
- Clean up Australia’s Ian Kiernan said he would listen to the kids, take on their ideas, and be The Keeper of the Challenges for their first conference in 1996.

**Children’s environmental rights and youth voice**

The idea of Millennium Kids leading their own conference on children’s rights to a safe and healthy planet followed their excursion to the UNEP UK Leave It To Us conference in 1995.

> Agency is the sense of control that you feel in your life, your capacity to influence your own thoughts and behaviour, and have faith in your ability to handle a wide range of tasks and situations. Your sense of agency helps you to be psychologically stable, yet flexible in the face of conflict or change (Serfontein, 2021).

The Children’s Environmental Rights Initiative seeks to ensure that children’s rights are placed at the centre of environmental decision-making and action. Its overarching goal is to secure international recognition of children’s fundamental right to a safe and healthy environment (CERI 2023).

The idea consolidated when they saw a video of 12-year-old Severin Suzuki speaking at an Agenda 21 conference in Rio de Janeiro in 1992; they saw that children could speak at adult events and be heard and listened to. It emboldened us all; it was taken as an imprimatur for making ‘Youth Voice’ the centrepiece of Millennium Kids.

> Youth comprise nearly 30 per cent of the world’s population. The involvement of today’s youth in environment and development decision-making and in the implementation of programmes is critical to the long-term success of Agenda 21 (UN 1992).

Sponsors and corporate support was sought from around the city. Five young people, their parents and I met around a table every weekend for months to design the first youth led [Kids Helping Kids](#) Environmental Conference. Kids set the agenda, planned the activities and guided the program. We workshoped how to approach local members of parliament to get support for projects and how to write letters to the local newspaper. We explored how the river and our transport systems had changed over time. We talked about waste and pollution and the things that mattered to kids. We had workshops and site visits.

At the first conference in 1996 180 children raised their concerns and needs. Trees, native animals, air quality, transport, energy, water, waste, and peace and lifestyle were their greatest concerns. They not only identified the issues they considered important but they also listed appropriate actions. They put their recommendations for change into a document titled Children’s Youth Challenges on the Environment. They invited the local Member of Parliament to be our voice in Parliament. The conference was opened by the Premier and closed by the Minister for the Environment.

The Kids conference concept was validated internationally. The Executive Director of the United Nations Environment Program in 1996, Elizabeth Dowdeswell, said:
Kids Helping Kids is a conference unique in its vision and unusual in its scope. For far too long we have denied ourselves the opportunity of listening to our children, of heeding to their pleas for a better world, for a healthy environment, their questionings and their answers.

The Kids’ concerns were sent to government departments and the replies trickled in. One department asked for a meeting.

Walk, ride, catch a bus to school was on the Kids’ agenda as a challenge to improve traffic congestion issues around schools and to keep local air clean. State government officers asked the kids how they thought travel behaviour to school could be improved. TravelSmart to School was launched in 1997 with young people at the helm.

Rather than adults writing the curriculum for kids, young people were given the problem to solve. They were asked to identify ways to reduce car use for getting students to and from school. The Kids gathered and collated baseline data through surveys and individual passports that recorded travel behaviour to and from school. They developed fun and interactive play ideas to engage other students, they developed their own radio commercials and posters. They identified constraints, barriers and solutions, and engaged with stakeholders.

Critically, the program wasn’t just interested in participant numbers, it was interested in behaviour change. A 10% reduction in car use to school was set as the target. The program was a game changer. It highlighted the difference between learning and behaviour change. From this point forward behaviour change was a consideration in designing all program and projects. These were exciting times but we underestimated how stubborn adults can be, and their ability to appear to listen and not hear or act. The big question from this time was: what actually changed when youth voice and engagement were embedded in the curriculum framework? There were highs and there were lows.

The lows:

- The keynote speaker for the first Kids conference pulled out a few weeks before the conference, reinforcing how seriously the kids voice was taken.
- Government Ministers played politics with a Kids event

The highs:

- The Kids wanted more, they were committed.
- Millennium Kids was incorporated in 1999 with a Youth Board central to the decision-making processes of the organisation.
- The Kids Helping Kids conference ran for 8 years, from 1996 to 2003, with hundreds of young people from local, regional and global communities coming together in WA to share and pitch ideas, shape youth-led local change and shape the future environmental education agenda.
- The Kids realized that advocacy was nothing without action.
- Behaviour change was on the agenda.

Developing flagship projects and the triple bottom line

Developing flagship projects and the triple bottom line theory expands conventional business success metrics to include an organization’s contributions to social well-being, environmental health, and a just economy. These bottom line categories are often referred to as the three “P’s”: people, planet, and prosperity (Elkington, 1997).

Millennium Kids embraced the triple bottom line idea, albeit a little unconventionally. The Millennium Kids triple bottom line (3BL) became: 1. have fun (indicated we were looking after people), 2. eat chocolate (an analogue for prosperity) and 3. care for the environment. This triple bottom line made the kids giggle but it has served Millennium Kids well because in all this we need to look after each other and embrace the fun in the world. When working with kids fun must never be forgotten.

Millennium Kids went from strength to strength as an incorporated not-for-profit. The budget allowed for paid staff for the first time, funded through income from sponsorship and grants. School communities were encouraged and supported to adopt bushland adjacent to or a short walk from their school. Trees were grown.
and planted. Partnerships were developed with local government in the city and the bush, and programs were expanded to plant trees on farms. As the education landscape changed, so did Millennium Kids. Environmental education was embedded in the sustainability curriculum and Millennium Kids’ ability to link and communicate between different agencies, levels of government and others maintained relevance.

At the 2001 conference a postgraduate student, Suzanne Johnson, interviewed the young attendees as part of her research toward her thesis titled “The Children’s Voice: Their concerns and search for a role in influencing the Environment”. Johnson’s findings noted children’s concerns relating to waste, forests and forestry practices, native flora, native animals, energy and consumption of non-renewable resources, pollution, oceans, global warming, salinity and commitment to the environment. Millennium Kids’ participants have continued to share these concerns over the years.

The Conference Kids told Johnson they wanted to be more ‘hands on’ to improve the environment, and they wanted an active role to help spread the environmental message. They also wanted to have an influential role in environmental education but, more than anything, they wanted to be heard. Overwhelmingly, kids told her they were not being listened to. They felt their ideas had low credibility with decision makers, that they had little influence, and they were seen as inexperienced and incapable. Essentially, they felt powerless in an adult world.

These conversations drove the ‘skills for life’ youth voice and engagement methodology that Millennium Kids applies to this day. Millennium Kids had to get a lot smarter about empowering children and to find and make ways to integrate with key programs, projects, agencies and services. Millennium Kids influenced curriculum and policy and mainstreamed youth voice, but traction was still limited and it was difficult to get up-take in some cases. There were highs and lows.

The lows
- Seeing school bushland get bowled over for development
- Some good projects and bush sites were abandoned because of lack of leadership following teacher replacement or burnout.

The highs
- Millennium Kids designed the first Clean Up Australia curriculum for schools, embedded in surveys of waste and ways to reduce waste at school.
- Building on behaviour change principles the team had input on activities and ideas that would encourage young people to make sustainable change with waste behaviours around schools.
- In a partnership between the Ministries of Environment and Education at federal and state levels a sustainability education framework was developed.
- A child 8 years old held her primary school to account. With a petition signed by her peers in hand she called on the adults to listen to kids. Plans to bowl over a cricket pitch and cut down trees to build a carpark were aborted after a lot of strategic advocacy, a community education campaign and consultation program.
- Millennium Kids was mentioned in We are the Weather Makers (Flannery, 2006)
- The Commissioner for Children and Young People was appointed in WA.
- Millennium Kids was contracted to develop partnerships with youth voice and engagement as the centre piece for understanding youth issues (but none of them centred on the key concerns of children about the state of the environment).
- In 2010 Millennium Kids funded two representatives from WA who joined the Australian NGO Child’s Rights Steering Group in Geneva to put climate change on the agenda.

To thine own self be true

In 2019 youth voice had to take a different direction. Kids were tired of voicing their concerns and being sidelined with photo opportunities but no action. The global youth strike movement had begun. Kids took to the streets, with some Millennium Kids included, in a global movement in protest of not being listened to. About this time the Millennium Kids’ Youth Board learnt of the divestment movement (Ayling & Gunningham, 2015) and were
asking questions about meaningful partnerships. They asked ‘where are we getting our funding?’ ‘What do our sponsors stand for?’ and “Do they take climate change seriously?’ ‘What are our sponsors actually doing?’ It was time to review what Millennium Kids stood for.

The Youth Board wanted a more transparent and strategic approach to partnerships and decided to quietly forgo corporate sponsorship for a time and to reclaim its values. The Governing Council agreed. Was there a downside? It was quickly discovered that alternative grant and philanthropic avenues are extremely limited and very competitive. The staff of five reduced to one part-time person.

There are a lot of pathways to change and different strategies work for different people. Millennium Kids built a new engagement model that celebrated the synergies of education, behaviour change, innovation and design, advocacy, community action, and rules and regulations. Millennium Kids sought ways for young participants to steer their passion projects in ways that suited them. Every child who now joins the program is invited to pitch a project to develop a real-world solution to a real-world challenge. They decide how they want to activate their project. This is the 1000 Actions for the Planet Toolkit, with the projects registered with the UN against the Strategic Development Goals.

Refusing to be greenwashed has clarified why Millennium Kids does what it does. It has been hard, but it has made Millennium Kids more strategic and efficient. When the Kids won the National Banksia Award in 2020 they were asked how such a small organisation has achieved so much.

The lows

- That Kids needed to take corporations and governments to the courts to safeguard their future.

The highs

- Kids took a class action against the Federal Minister for Environment, arguing that the Minister had a duty of care to protect young people from climate change, and that this needed to be a consideration in approval processes for projects that would produce greenhouse gas. The Kids win was overturned on appeal but they certainly started a conversation.
- Abby, the Millennium Kids’ Chairperson’s daughter, came running down the stairs clutching a copy of *The Power of Positive Pranking* (Amoore, 2022) after Christmas in 2021. We knew she had stumbled on some pretty cool news. Author Nat Amoore had referred to the Millennium Kids website in her book – to inspire young people to make positive change in the environment.
- I was invited to join a UNESCO Future of Education round table. The world of education is changing to focus on real world skills for real work challenges and the Millennium Kids process was on the agenda. Millennium Kids processes were recognised by a global audience of future-thinking educators.

**Future Thinking**

In 2017 all Millennium Kids programs were reviewed by 100 young people at a 3-day conference. Deforestation, waste and climate change were again the top three challenges. The conference focussed on futures thinking and the bold ideas to create a vision for 2050 and plan a pathway to get there. The Kids thought what needed to be done was obvious and spent time setting the agenda. The Youth Board designed 3 major projects that responded to these collective concerns of young people. To support these projects Millennium Kids rebuilt the website, with an 11-year-old as project manager, and began two major new projects.

**Agents of Climate Change**

To tackle climate change the Youth Board stepped up in their advocacy role and attended more meetings with decision makers. At the beginning of the pandemic, frustrated at the lack of climate action education in schools, they voted unanimously to co-design a deliberative democracy program that had climate education and action at its core. They trained with Prof Janette Hartz Karp for 18 months through online and face to face sessions. They trialled their program across the state and reviewed it based on youth feedback. The *Agents of Climate Change* program was born.
The Agents of Climate Change program profiles science-based and empowering resources for teachers. Students get to explore climate challenges, discuss the big issues, and ask the big questions of experts. They get to deliberate, exchange ideas, and pitch ideas for local change. Their recommendations are presented to stakeholders and selected projects receive funding and support to make them real. The program is currently funded by the United States Government (via the US Consul in WA) and some WA local governments. The youth message is clear:

*We are representatives from Millennium Kids who are concerned about the delivery of education around climate change issues particularly for young people.*

*We need better ways to empower young people – not just teacher directed projects and one-hour lessons on climate change that leave us anxious and disempowered. We want more programs where youth research and create solutions to climate change showcasing their innovative thinking. We need 21st century skills to tackle real work issues preparing us as future thinkers and changemakers (Millennium Kids Youth Board, June 2023).*

**Green Lab**

Children as young as seven have contacted Millennium Kids at times over matters like the felling of black cockatoo foraging trees. Kids understand the connection between trees and birds. They know birds need feeding trees as well as nesting trees. They know the birds have adapted to urbanisation and land-use change and now forage on non-native species. They know canopy cools the planet.

The Green Lab program was born out of these contacts and of community frustration at the ongoing loss of tree canopy across Perth’s metropolitan area. Bushland continues to be cleared for new school buildings and sporting facilities. Revegetation programs are declining because of lack of monitoring or succession planning. Resources are being wasted, conservation assets are deteriorating, and dedicated teachers are not getting essential strategic direction and support. Needing all stakeholders to work together to increase canopy to cool our city seems so obvious.

Councils are including school canopy cover when they map canopy areas across their municipalities, and clearly schools have a pivotal role in protecting, monitoring and increasing canopy. A youth-led program could drive protection, monitoring and increasing canopy on school sites across cities in partnership with all stakeholders. In 2020 Green Lab won a state Natural Resources Management Grant to develop a three-year pilot program. Learnings from the previous 20 years were brought to the table, we learned more and had some wins. A positive precedent was set when a local government and a primary school collaborated and signed a 15-year lease agreement to protect and maintain the school’s bushland. Another school removed an asphalt basketball court and planted an outdoor classroom.

Millennium Kids built their new website to host school projects, to track change, to showcase a series of Green Lab case studies and highlight their innovation to inspire teachers, students and others. Millennium Kids is currently designing a Green Lab 5 Star Rating system to acknowledge and potentially reward schools – i.e. a school incentives program. The rating system will consider criteria like whether bushland education is included in all classes, whether bushland protection embedded in school strategic plans, whether new principals will be selected based on their support for sustaining established environmental education practices, projects and assets, and whether students are heard on environmental issues and given due regard and support in decision making and project implementation.

Working with Noongar Elders and their community Millennium Kids is researching the stories and names for the area and building cross-curricular opportunities through the Caring for Country Framework. The kids want to activate a conversation across Perth during the 2024 Western Australian Tree Festival.

The lows

- The world is getting hotter
- Perth has the lowest canopy coverage of any major city in Australia
- Use of the term *global warming* has progressed through to *climate change* and *climate crisis* and now *global boiling* is being discussed
The highs

- The Kids keep coming and they are getting louder.
- Watching current flagship projects, Green Lab, 1000 Actions for the Planet, and Agents of Climate Change come to life.
- Perth’s local government authorities are engaging with young people through the Agents of Climate Change program as part of their Climate Change and Energy Transformation Strategy.
- The Royal Automobile Club (RAC) of WA has invited the Kids to codesign and lead a youth leadership program that focuses on sustainable change in their organisation.
- The link between climate anxiety and the mental health of young people is finally on the agenda

Conclusion

Since 1995 young people have achieved and grown through Millennium Kids. Millennium Kids has always had a multi-stakeholder model. Starting as a little independent group working alone, trying to influence change for the environment, Millennium Kids is now part of a global collective. The Kids use their iPhones to find precedents around the world that support their ideas. They are networked and active and bolder. They influence the global collective and they bring global messaging back home to use. Youth Board member Amelia has worked with hundreds of young people around the world to lead the development of the MOCK COP Youth Statement on Climate Education which she will present at COP 28 in Dubai in December 2023. Alumni now fill roles in government, corporations, in leadership roles locally, regionally and globally and they report back from around the world.

Programs now feature youth-led voice and engagement at local, regional and international level. Millennium Kids has its own version of the circular economy. Green Lab is gaining increasing recognition. The World Economic Forum awarded the project a Top14 Global Innovator Award. A Green Lab member, Aelwen Johnstone, has been invited to speak at the Second World Forum on Urban Forests in Washington, DC in October 2023 - the only young person invited to speak. Back home, the kids still want their river back. They want the freeway underground and an avenue of trees, with plants for birds and insects.

In 2023 the world is shouting “Humanity depends on the boundless energy, ideas and contributions of youth everywhere. Today and every day, let’s support and stand with young people in shaping a just and sustainable world, for people and planet.” (Guterres, 2023). The children no longer use terms like ‘challenges’ or ‘recommendations’. They are demanding. Are we listening? Do we hear them? Will we engage with them by providing meaningful, skill-building opportunities and will we support them by having them at the table? Will you be a role model for change? Will you put your own work under the microscope and claim your agency? Our kids depend on it!

References


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Abstract

Climate change presents significant challenges for plants and plant selection. Temperatures are increasing, and rainfall is changing faster than plant species can adapt. This means that many species that we plant today may no longer cope with the future climate. This may be exacerbated in urban environments where impervious surfaces and the urban heat island effect enhance the stressful environments for urban plants. One novel method to select urban trees for future climates is based on climate niche analysis. Using global databases, the current climate niche of a tree species is extracted and compared against the predicted future climate at a given location. If the climate niche of a tree is not matched with the future climate niche of a city, then that tree species is deemed no longer suitable. These types of climate niche analysis are very common, and they are already influencing management and tree species selection decisions. For example, in the City of Melbourne over half of the current species have been deemed ‘unsuitable’ for a future climate based on climate niche predictions and species are getting replaced. Botanic gardens have developed climate niche tools for selecting ‘climate proof’ tree species. However, this climate niche approach is not without problems, and many potentially suitable tree species are being excluded because their distribution in nature imposes is likely a poor indicator of their tolerances. In this paper we critically examine this tree selection approach and highlight the “good, the bad and the ugly” of this and other methods and give examples how species selection could be improved.

Introduction

Tree species selection for future climates is a significant issue for urban planners. Our climate is changing rapidly but tree species are long-lived organisms. Is the climate changing so fast that some species can no longer grow, thrive and survive? There is surprisingly little data if urban trees are increasingly stressed. Many municipalities collect urban tree inventory data, but at the same time have a poor documentation on the reasons for tree species poor health, removal or replacement. Consequently, there is very little empirical evidence that large proportions of the urban forest are impacted by changes in climate. It is thus most surprising that several recent studies based on climate niche analysis suggest that the majority of urban tree species are at significant risk from the impacts of climate change (Burley et al., 2019; Esperon-Rodriguez et al., 2019; Kendall and Baumann, 2016). A recent study suggests that over 70% of tree species in urban centres will be at risk from projected changes in annual precipitation and mean annual temperature (Esperon-Rodriguez et al., 2022). These numbers are staggering and cause concern among urban foresters. However, a closer investigation of the study and the methodology would suggest that there is little evidence that trees in the urban forest will be severely impacted by changes in climate. There are key limitations in the methodology of climate niche analysis, flaws in the application of the safety margin concepts. Furthermore, there is a lack of consideration as to the tolerance mechanisms that many tree species possess to tolerate stress, and their capacity to adapt and acclimate to changing environmental conditions.

Climate niche modelling

A key methodological component of many recent studies on climate suitability of urban trees is climate niche analysis. This methodology calculates the climate niche of a species based on global occurrence databases like the Global Biodiversity Information Facility (GBiF) and climate data like WorldClim. The occurrence data of a species are matched to mean climate data for that location. The climate data are parameters like mean annual temperature or mean annual precipitation, but others like aridity indices or mean precipitation of the driest quarter are also used. The data are then plotted to evaluate the ‘climate niche’ of a species (see Figure 1). Key percentiles are calculated from the climate niche of each species to represent critical limits. For example, the
90th percentile for mean annual temperature has been used as an upper thermal limit. Species would be considered vulnerable if they were to be planted in a city which is predicted to have a mean annual temperature greater than the upper thermal limit. The future mean annual temperature of a city might be predicted to be 19.5 °C and this would be at the edge of the current occurrence records (at the 98th percentile), then that species would be vulnerable. If the predicted mean annual temperature would be 17.8 °C and that would correspond to the 70th percentile of distribution, then that species would not be vulnerable.

![Graphs showing climate parameter vs. occurrence](image)

*Figure 1. Example of a climate niche analysis of a tree species. The graphs show the number of records plotted against a climate parameter such as mean annual temperature or mean annual precipitation. Some publications assume that a threshold is reached when the climate of a city is outside the 10th or 90th percentile of the distribution for a given species, left figure (Esperon-Rodriguez et al., 2022). I.e. the current or future climate of that city is drier or hotter than most of the occurrence record for the species. Others are a bit more nuanced and assume high vulnerabilities if the future climate of a city is approaching the edges of the current distribution of a species, right figure (Kendall and Baumann, 2016).*

### Issues and limitations of climate niche modelling

At first glance this approach seems very logical and straightforward. We are lucky that we now have vast databases with occurrence records for many global plant species and that these can be matched with excellent climate records. Thus, the data are regarded as valid.

However, all climate niche analyses have several limitations. The data provide only information where plants currently or historically occur. But they do not provide any information about the locations where the species cannot occur. This is an important distinction: the absence of a data point does not mean that the species cannot exist in that climate or that part of the globe. It only means that it has not been observed there.

A second limitation is that the occurrence data do not provide any information about the number of plants observed at the one observation point. It could be a single tree on the side of the road, or it could be a forest with 100,000 trees. However, in the database these two observations are equally weighted, they just count as one data point. Conversely, there are other cases where many individual tree occurrences have been uploaded for the same location (e.g. *Platanus x acerifoila* for New York City), thereby biasing the occurrence vs climate record to one climate point. We also do not have information about the health status of the observation, if the tree was healthy, free of any damage or a poor and struggling specimen. And of course, we assume that the people collecting the data, which can be anyone, are properly trained in species identification.

The third and probably most significant limitation is that in most instances the occurrence record reflects the sum of all biological processes that led to the natural establishment of a plant at that location. In other words, it reflects the realised climate niche in nature (Soberon and Nakamura, 2009). This is displayed in Figure 2. Under natural conditions a plant will undergo a range of natural processes from flowering, to seed setting, seed distribution, seed germination and plant establishment (Young et al., 2005). All these processes are influenced.
by climate and each of the processes has a distinct climate niche. Some have broader climate niches than others, and it is usually the establishment niche that sets the climatic limit to where plants naturally occur, as a young plant is very vulnerable to climate during the time from seed germination to the establishment. However, a mature plant usually has much greater climatic tolerances and thus has a much broader climate niche. The climate that a plant can tolerate is called the **fundamental climate niche**. The issue is that the fundamental niche of most plants is unknown and that the climate niche that can be calculated from occurrence records reflects the realised niche of a species (Booth, 2018). Most records are observations of botanists in nature where plants would have undergone the natural processes described above.

![Figure 2. Example of the various climate niches at different stages of the life cycle of a plant. The reproductive niche (green) indicates the climate suitable for processes such as flowering and seed setting. The dispersal niche (blue) is the climate where seeds can be distributed. The establishment niche (red) is the climate in which seeds germinate and a young plant establishes, which is usually the smallest niche as it is the most vulnerable phase of a plant. The adult niche is the climate in which a mature plant can exist, and this is usually much greater than the other niches. However, in nature and without human intervention the realised climate niche is set by the narrowest niche, in this case the establishment niche. Data are for illustration purposes only, modified after (Young et al., 2005).](image)

However, there are a few examples of species where global occurrence data more likely represent the fundamental niche. These are species that have been grown commercially in plantations and this has increased their distribution relative to their natural distribution. The natural range of *Pinus radiata* was a very restricted climate near Monterrey in California – thus its name Monterrey pine (Rogers, 2002). Now it is a major soft wood species in Australia and New Zealand covering a vast climate niche. The range of mean annual temperature within the natural distribution of *Eucalyptus cladocalyx* (sugar gum) in Australia was 14-17 °C, but it was grown successfully at some sites in Africa where the mean annual temperature was as high as 21 °C (Booth 2017). The native distribution of *Eucalyptus globulus*, the Tasmanian blue gum, is on the island of Tasmania and the southern ranges in Victoria. Hence, it had a very narrow geographical and climatic distribution in its realised niche in a cold and high rainfall climate. Any climate niche analysis would classify this species as highly vulnerable to increases in temperature or decreases in rainfall. However, today it is grown as a plantation species in almost every continent and inhabits hot and dry Mediterranean climates of California, South Africa, Portugal and Spain.

These examples show that the fundamental climate niche of a species is invariably much greater than the realised climate niche that can be discovered from the global databases. For predictions of climate suitability in natural environments this may not matter as natural processes still dictate species distribution, thus the realised niche is relevant. However, in urban centres all the processes that determine the ‘realised niche’ are...
inconsequential. Tree species are planted as 2-4 year old saplings and nurtured for a period time until they are established. The use of the Global Urban Tree Inventory database (GUTI, Ossola et al., 2020) is one step towards a better approximation of the fundamental niche, but it still has the same limitations. GUTI contains occurrence data of 4,734 tree species in 473 urban areas. However, if a tree species does not occur in a certain urban area, it does not mean that it cannot grow there. It just means that it has not been planted there, or that it was not recorded.

**Issues and limitations of climate data**

Another major limitation of climate niche analysis is the type of climatic data that are used. These are invariably mean climate data, such as mean annual temperature, mean annual precipitation, mean temperature of the driest month, or mean precipitation of the driest quarter. These values give an idea of the general climatic conditions, if the climate is warm, moist, if there are dry periods or frost periods. But these values are bad predictors of the climatic stresses or extremes that urban trees will experience. Trees will not be impacted or killed by mean annual temperature or mean annual precipitation. They are killed by long periods of drought, unseasonal periods of drought, heatwaves in the middle of a drought period, storms, floods or pest and disease attacks during periods of stress. None of these can or will be measured by the mean climatic parameters used in climate niche analyses.

**Figure 3. Cumulative rainfall for the City of Melbourne (Australia) for all years since 2000.** The graphs show a large interannual variation of rainfall, with a variation of 370 mm of annual rainfall in dry years (2019) and 840 mm of annual rainfall in wet years (2011). Data source: http://www.baywx.com.au/accumall.html

Even if mean climatic variables could be linked to tree performance in a meaningful way, they are not representative of the climate experienced by urban trees. The City of Melbourne in Australia has a mean rainfall of 650 mm according to the long-term average recorded in the main climate station near the city centre (Figure 3). However, the metropolitan area of Greater Melbourne experiences a mean annual rainfall of 450 mm in the west and over 1000 mm in the east. Thus, the actual variation of annual rainfall that tree species are potentially exposed to in Greater Melbourne can be much greater or smaller than the average. And within these values there is the year-to-year variation, which for the City of Melbourne ranges between 370 mm in dry years and over 800 mm of rainfall in wet years (Figure 3). Most urban trees tolerate this typical annual variation without
any problems even though the mean annual rainfall of the extreme years would exceed the high or low thresholds (5th or 95th percentiles) of the species climatic niches.

Another issue is microclimate. The mean weather station of a city will not measure or detect the large variances that are created based on local microclimate. The central business district of many cities is often much warmer, has greater mean temperatures but also greater extreme temperatures due to the urban heat island effect. Contrary, trees in parks or near streams often experience much milder temperatures. In terms of rainfall, cities have many impervious surfaces, so much of the rainfall will not reach the root zone in densely built areas. On the other hand, cities also have additional sources of water that is accessible to trees, like leaking water pipes, or stormwater drains that get accessed by tree roots. The extent of this water access in most cities is unknown but also unquestionable. Thus, mean rainfall data are undoubtedly a very poor climate predictor for urban trees, as water access cannot be predicted for most urban trees.

**Tree species issues**

Most trees that are planted in urban areas have very little in common with their native counterparts. Many urban trees are hybrids, carefully bred for form and function to grow in the urban environment. They are often specific cultivars with limited or no genetic variability. The genetic source of trees is often unknown, or trees have been hybridised with other species so that there is no native equivalent (e.g. London plane, *Platanus x acerifolia*). Some urban trees are also grafted, where scion and rootstock are from different species or cultivars. Thus, it is difficult to assess to what degree the highly bred and cultivated urban tree would be represented by the wild-forms and therefore climate niche of the native trees of a species.

**Tree stress response strategies**

Climate envelope analysis in urban areas treats tree species equally in their response to climate and stress. As such, no allowances are made for diverse responses, adaptations, adjustments and acclimations. The climate niche method requires this over-simplification, but of course it is not based on reality. Tree species exhibit a large variety of responses and tolerances to stress, and these are difficult to predict and, in most cases, not well linked to climate parameters. The reason for this is that trees have evolved various mechanisms to drought or heat stress (Figure 4, (Levitt, 1980)). Some trees resist drought by avoiding drought stress through deep roots and access to deep soil moisture or groundwater. These trees maximise water uptake and are water spenders, but often have very vulnerable water conducting tissues. Others avoid drought stress through transpiration control; thus, these species minimize water loss and are water savers, and often have more vulnerable water conducting tissue. Other trees tolerate water deficit and drought stress by having more drought tolerant tissues and these species have less vulnerable water conducting tissues. Interestingly, species with various strategies can co-exist in the same environment (McDowell et al., 2008), although they can have different vulnerabilities. This highlights the flaw in using climate envelope as an indicator for tree vulnerability.

A climate niche analysis also assumes that trees are static in their climate responses and cannot acclimate. However, there is broad literature that many species can acclimate to higher or lower temperatures and e.g. adjust photosynthesis and respiration (Atkin and Tjoelker, 2003; Wang et al., 2020). This means that higher temperatures do not necessarily damage trees, in fact they can be advantageous. We assessed the temperature optimum of ecosystem photosynthesis (gross primary production) of different forest ecosystems in Australia using eddy covariance data from flux towers (Bennett et al., 2021). This showed that the ideal temperature for photosynthesis of most forests was well aligned with their mean annual temperature. However, the trees had a temperature buffer and could tolerate higher mean annual temperatures. We then modelled how these forests would perform under climate change to assess the climate vulnerability of each forest using the Australian CABLE model. Most forest ecosystems increased photosynthesis and biomass by 40% in a future climate by 2080 and only water limited Mediterranean woodlands showed lower increases or no change (Bennett, Arndt et al, unpublished data). However, no forest system was worse off, highlighting that the assumption of warmer climate equalling ‘risk’ or ‘bad outcomes’ is oversimplified and at times plain wrong.
Figure 4. Schematic representation of the various strategies of plant responses to drought. One strategy of drought resistance is ‘escape’, where plants complete a life cycle when conditions are favourable, e.g. many desert annual herbs or geophytes. Drought ‘avoidance’ can be achieved by either ‘water spending’ where species with deep root systems access deeper soil moisture reserves and never experience drought. Eucalyptus camaldulensis, river red gum, is one example. Drought avoidance can also be achieved by ‘water saving’ or reductions of water loss, either by small leaves, carefully controlling transpositional water losses or by dropping leaves. Pinus edulis (pinyon pine, controls transpiration) or Platanus x acerifolia (London plane, drops leaves) are examples of this strategy. Plants that are drought ‘tolerant’ can withstand longer periods of drought by enduring water deficits thorough physiological or morphological traits or adjustments. Many eucalypts occurring in dryer environments, but also Callitris, have cavitation resistant tissues and are truly tolerating drought. Modified after (Levitt, 1980).

Use climate niche modelling with caution

We caution against only using climate niche models for assessing tree species vulnerability and therefore future urban tree selection. As outlined above, the analysis is overly sensitive, and the applied vulnerabilities may be statistically justified but not biologically relevant. In fact, climate niche modelling can have negative consequences for tree species selection. Currently 21% of species in the city of Melbourne are assessed as potentially vulnerable to climate change (Kendall and Baumann, 2016). The species were labelled red, amber and green according to their vulnerability and this was taken literally by tree planners. One tree species that was tagged red (climate vulnerable) is Eucalyptus leucoxylon (yellow gum). The species is a drought tolerant woodland species that is outcompeted by faster growing eucalypts in wetter forests, resulting in a narrow climate niche. However, it is an ideal street tree: medium height, drought tolerant, robust. There is no evidence that it is vulnerable to climate change. However, the urban forest strategy of one Melbourne council labelled it drought and heat sensitive in its urban forest strategy (Council, 2017) and this species struggled to sell by commercial nurseries in Melbourne in subsequent years (H Mitchell personal communication). Thus, the outcome of climate niche analysis will likely lead to an over selection of species from warmer climates, while trees growing in colder climates will disappear from our cities. Many of these species will likely grow perfectly well in a future climate, but they are no longer planted. If there is scientific evidence that these ‘colder’ trees will perform badly in a warmer climate then by all means, deselect them from a future urban forest. However, there is still very little evidence to support the claim.
Conclusion

There are alternatives to climate niche analysis. Cities and urban planners can rely on the experience and expertise of their arborists and urban foresters as they assess the performance of urban trees on a regular basis. Expert opinion matters and in lieu of better scientific data would be preferrable to only relying on climate niche analysis data. It would be very powerful if urban tree assessments made by arborists in many towns and cities could be collected and archived in accessible databases so that data can be shared, similar to the way occurrence data is shared in the Global Biodiversity Information Facility (GBIF).

An alternate approach that relies on local tree assessment is the sister climate city analysis (Hancock, 2022). The urban forest of a city with a future analogue climate will be used to select tree species that are growing well in this future climate sister city. There are multiple climate analogue explorer tools for the US (US-Climate-Analogue-Explorer) or Australia (Climate-Analogues-Australia). However, this requires that each city has up-to-date inventories and a detailed health assessment of the tree species in that city.

Whilst there is a desire to develop easy ‘click and go models’ for selecting tree species for future climates in urban centres we caution against these models if they are only based on climate niche analysis. As we have outlined above the selection of a tree that is climate resilient is complex and depends on many variables. It depends on the tree’s drought and heat resistance strategy, its suitability as an urban tree, its ability to adjust or acclimate to different climate conditions. Much of this information is not known for most species, but much of it can be extracted from urban inventories. However, this legwork is required if urban foresters are to make good decisions for species selection for the future urban forest. Using simple climate niche models can be a part of the process in identifying widely distributed species – but not in assessing the proposed vulnerability of species.

Acknowledgements

We wish to thank Dave Kendall and Alessandro Ossola for many stimulating discussions on the topic of climate niche models, their advantages and limitations.

References


THE DEMANDS WE PLACE ON STREET TREES: A CASE STUDY OF EUCALYPTUS LEUCOXYLON F.MUELL.

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Abstract
Given that there has been relatively little research into Australian species for use as street trees compared to major exotic genera, yellow gum, Eucalyptus leucoxylon F.Muell. is one of a few eucalypts occurring in south-eastern Australia with bright coloured flowers that is highly regarded for urban use. However, are there species characteristics and performance traits that underpin this high regard? For the most part the arboriculture of yellow gum is unknown and undocumented. This brief paper explores some of the criteria that could be considered valuable for a tree growing in Australian streets. The performance of 300 E. leucoxylon street trees growing across the city of greater Melbourne were assessed against these arboricultural criteria that related to canopy structure and density, straightness of the trunk, health (assessed on canopy, trunk and branch condition, production of exudates and presence of fungal fruiting bodies), flower colour and root systems. The results showed that E. leucoxylon was a suitable street tree species with most specimens showing good habit, vigour and health. The trees’ live crown ratio, height, flower colour and capacity to cope with pruning were considered appropriate for a well performing street tree. Their dense canopies and high live crown ratios provide shade that can reduce the urban heat island (UHI) effect. Yellow gum has the potential to be a successful street tree well beyond it natural range, and not only in Australia but in other parts of the world where it has been successful.

Introduction
We demand a great deal of our street trees. We want them to grow fast but not too fast, establish quickly, have a single stem and a full, dense and spreading canopy. We want them to be attractive in foliage and flower, but would prefer that they don’t shed leaves, flowers and fruits. We want them to live a very long time but require no maintenance and we don’t want them to cause damage to infrastructure or during storms. There are many more attributes that we want, but you get the point. We want all of this and want it from Australian native species that have never been selected or bred for urban use or had their performance as urban street trees assessed.

Elite specimens of Ulmus, Quercus, Platanus and Fagus have been developed over centuries for urban use, but there has been little research into the selection, breeding and performance assessment of Australian street tree species. For many Australian trees the only data available pertains to high value forestry species, few of which are widely used as street trees. There has been work on different provenances of spotted gum (Corymbia maculata) for urban use (Bone 2001) and Williams (1995) tested provenances of brush box (Lophostemon confertus) for growth rate and waterlogging tolerance. Both studies noted high intraspecific variation that could be used for selection of elite individuals.

The hundreds of eucalypt species are important components of the Australian landscape and with an inherent tolerance to environmental stresses and local soils many are regarded as potentially suitable for amenity use in a range of sites (Nicolle, 2002). The high level of variability within eucalypts for characteristics such as habit, size and shape of leaves, flowers and fruits and bark colour making selection for urban use worthwhile. Yellow gum, Eucalyptus leucoxylon F.Muell. is one of a few eucalypts occurring in south-eastern Australia with naturally bright coloured flowers and it is highly regarded as an important urban tree. Yellow gum is readily propagated from seed but the progeny show the variability and diversity typical of seedlings.

Typically a medium to small woodland tree of 13-16 m height (Boland and Brooker, 1975; Boland et al. 1992), E. leucoxylon ssp. leucoxylon and ssp. pruinosa in forest form can reach 30 m (Boomsma, 1981; Nicolle, 2006). It has a smooth trunk with yellow, blue-grey or cream patches, and rough fibrous bark retained for 1-2 metres at the base (Slee et al, 2006; Nicolle 2006). Flower colour ranges from white to red, but there are yellow and apricot...
variants (Boland, 1978; Slee et al, 2006). Red flowering individuals occur in all subspecies except *E. leucoxylon* spp. *pruinosa*, which is predominantly white (Slee et al, 2006).

Pryor and Johnson (1971) recommended four subspecies: var. *leucoxylon* (including var. *erythrostema* and var. *angulata*), var. *macrocarpa*, var. *pauperita* and var. *pruinosa*, based on fruit size, ribbing and glaucousness, but Boland (1978) recommended four subspecies representative of four geographic distributions: the Eyre Peninsula (ssp. *petiolaris*), coastal (ssp. *megalocarpa*), sub-coastal (ssp. *leucoxylon*) and inland (ssp. *pruinosa*). Two additional subspecies, ssp. *stephaniae* and ssp. *connata*, were described by Rule (1990), who elevated subspecies *petiolaris* to species level, and described subspecies *bellarinensis* (Rule, 1992; 1998). Natural populations of subspecies *bellarinensis* are subjected to cool, salt laden coastal winds, and sites that are water logged in winter (Rule, 1998), suggesting suitability for urban use. Subspecies *megalocarpa* is the most highly horticulturally exploited subspecies while subspecies *stephaniae* has semi-weeping foliage and may be more drought tolerant than other subspecies (Rule, 1991; Nicolle, 1997; 2006). Subspecies *petiolaris* (*E. petiolaris*) is regarded by Nicolle (2002) as one of the better subspecies of *E. leucoxylon* for street tree use as it has a graceful crown, more flower colours, is tolerant of saline soils, has a good growth rate and is a medium sized tree with large pendulous buds, flowers and fruit (Boland, 1977b; Nicolle, 1997; Bennell et al, 2008).

Interrogating the tree inventory data of the 31 municipal councils making up the city of greater Melbourne, identified nearly a million trees from 1127 different taxa with the proportion of Australian species being 60%, and 70% of the most frequently planted species were native (Frank et al. 2006). The most popular native species were from *Acacia*, *Callistemon*, *Eucalyptus*, *Melaleuca* and *Lophostemon* genera which comprised 43% of all trees (Frank et al. 2006), but the genus with the highest number of taxa and number of individuals was *Eucalyptus* and the most common species was yellow gum, *Eucalyptus leucoxylon* with over 20,000 individuals (Frank et al. 2006). Despite its common occurrence, the performance of *E. leucoxylon* in streets can be quite variable (Beardsell et al. 1993).

The aim of this research was to develop a set of tabulated criteria against which the performance of yellow gum as a street tree could be assessed. It was hoped that these criteria might then be utilised more widely to assess Australian native trees for use in streets and the urban forest more generally. The criteria could also be used to identify superior specimens for future propagation and planting. Once the criteria had been developed, they were used to assess *E. leucoxylon* growing across greater Melbourne, providing an interesting and relevant test case.

### Method

With an aim of assessing approximately 300 trees across greater Melbourne, it was recognised that sampling single trees in different streets involved too much travel time to be practical. So sampling was based on choosing streets at random where 3-5 *E. leucoxylon* trees could be assessed on a single visit. Suburbs were visited and locations where there were sufficient trees were identified so that trees could then be selected randomly for assessment. Trees were sampled randomly from a wide range of suburbs and situations across the city. Assessments were undertaken between the months of April and October. A more complete explanation of methods used and tables developed can be found in Moore and Chandler (2023). This paper presents some but not all of the Tables developed and some have been abridged and/or combined for the purposes of this presentation and for a more practical application of the criteria for use by arborists working in urban forests.

In selecting trees for assessment, the following criteria were applied:

1) Trees had a diameter at breast height (DBH at 1.3 m) of at least 10 cm,
2) There was clear access to the base of the trunk
3) Access was available to measure canopy spread in a north-south and east-west direction.
4) There was safe site access from vehicular traffic

DBH was used as the basis for selecting trees for assessment and while precise data on tree age was not available. All trees assessed were considered to be older than 10 years. Sufficient trees were identified to allow
300 specimens growing across the city to be assessed with the information and data gathered to be used to inform the criteria developed.

**Location, site and soil**
Tree position and a detailed description of the tree’s location on the street were recorded. Site soil surface and paving and any root damage to landscape infrastructure were also noted. Soil compaction was measured by pushing a 10 mm diameter, 1 m long steel spike into the ground within 1 m of the base of the tree trunk. Pressure was stopped when resistance was met. This was repeated three times, to ensure there was no obstruction to penetration and until there were three consistent measurements. The resistance to insertion was recorded on a five-point descriptive scale: Very soft, Soft, Medium, Firm and Impenetrable.

**Growth habit and phenotype**
Data were collected to provide a phenotypic description of *E. leucoxylon* trees growing across Melbourne (Table 1).

- **Height** measured from soil surface to the highest living canopy point using a heightmeter.
- **DBH** at 1.3m was recorded.
- **Canopy spread** measured across the drip line along north-south and east-west axes and the mean of the two values was used as the measure of canopy spread.
- **Canopy density** estimated using a 5 point scale <20%, 21-40%, 41-60%, 61-80% and >81% (Table 1).
- **General canopy habit** described using small images to ensure consistency and 5 descriptors: rounded, broadly round, oval, pyramidal or vase shaped (Table 1). Whether the tree had a single dominant leader, and the number of lower order major lateral branches forming the crown were recorded. The height to the first branch from the ground was measured.
- **Flower colour** was described using known flower colours; red, dark pink, light pink, orange, white and bi-colour was an added category to accommodate a specimen discovered during assessment.
- **Trunk taper** was determined by comparing the difference between the DBH and the stem diameter at ground level as a ratio (DBH/trunk diameter at ground level). Trunks were assessed for straightness and lean. Lean was the deviation of the trunk from the vertical and trunk straightness was described by whether there were bends or twists from ground level to the major lower order branch scaffolds.
- **Live crown** was measured as a proportion of the height of the tree measured to the highest living point in the canopy. The resulting ratio indicated how much of the tree’s height was occupied by its canopy. The higher ratio, the more impressive is the canopy in relation to a tree’s height and the more likely the tree is to provide shade and other benefits in a warming climate.

**Tree health and condition**
Trees were surveyed for health and the existence of any physical problems (Table 2). The presence of decay and/or fungal fruiting bodies was noted to determine whether *E. leucoxylon* was susceptible to attack by decay causing organisms. Insect damage was also assessed. Trunks and lower branches were assessed for the occurrence of resins and other exudates, the presence of which may indicate the presence of disease or decay in a tree was also noted.

Evidence of vandalism, poor pruning, damage from line trimmers, vehicle damage or wounds from ropes and cables was recorded. The loss of a leader or major lower order branches was assessed and the possible causes of the loss were recorded (Table 2). Given that most trees had a clear trunk which was designated as the primary structure (order 1), other branches were ordered (order 2, order 3....) from the trunk to the extremities of the canopy. As a stress, damage or wounding response, most eucalypts produce epicormic shoots and so the occurrence of epicormic shoots was recorded.
### Table 1. Phenotypic characteristics relating to tree size, canopy, trunk, branching and flower colour, their description, and the category or unit of measurement recorded.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Description</th>
<th>Categories / units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tree height</td>
<td>Using a Silva® clinometer, the top of the tree was sighted from a predetermined distance (usually 20m), and the correlating angle recorded.</td>
<td>(m)</td>
</tr>
<tr>
<td>Diameter at breast height</td>
<td>Measured at 1.3m</td>
<td>(mm)</td>
</tr>
<tr>
<td>Canopy spread</td>
<td>Average of canopy spread in a north-south and east-west direction</td>
<td>(m)</td>
</tr>
<tr>
<td>Canopy density</td>
<td>Estimated by below looking upwards through the canopy</td>
<td>1. &lt;20%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. 21-40%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3. 41-60%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4. 61-80%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5. &gt;81%</td>
</tr>
<tr>
<td>Canopy shape</td>
<td>Canopy shape</td>
<td>1. Rounded</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. Broadly round</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3. Oval</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4. Pyramidal</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5. Vase</td>
</tr>
<tr>
<td>Number of main branches</td>
<td>Number of branches holding the majority of the canopy</td>
<td>1. One branch (single stem)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. Two branches</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3. Three branches</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4. Four branches</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5. Five + branches</td>
</tr>
<tr>
<td>Dominant leader</td>
<td>Does the tree have a dominant leader</td>
<td>Yes/no</td>
</tr>
<tr>
<td>Main branch position</td>
<td>The height to the first main (lower order) branch – including missing branches.</td>
<td>(m)</td>
</tr>
<tr>
<td>Flower colour</td>
<td>Flower colour was described using the known flower colours for <em>E. leucoxylon</em></td>
<td>1. Red</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. Dark pink</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3. Light pink</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4. Orange</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5. Yellow</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6. White</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7. Bi-colour</td>
</tr>
<tr>
<td>Trunk taper</td>
<td>The taper between DBH at 1.3m and at the base of the trunk</td>
<td>Ratio: DBH / Diameter at base</td>
</tr>
<tr>
<td>Trunk straightness</td>
<td>The amount of twisting and kinks present in the main trunk</td>
<td>1. Very straight</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. Reasonably straight</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3. Bark twisted, moderately straight</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4. Trunk moderately kinked/twisted</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5. Trunk severely kinked/twisted</td>
</tr>
<tr>
<td>Trunk lean</td>
<td>Categories are independent of trunk straightness</td>
<td>1. No lean</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. Minor lean</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3. Major lean</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4. Extreme lean</td>
</tr>
<tr>
<td>Live crown ratio</td>
<td>When observing the full tree profile, the proportion of height which has live crown, is deemed the live crown ratio</td>
<td>1. &lt; 20%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. 21-40%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3. 41-60%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4. 61-80%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5. &gt; 81%</td>
</tr>
</tbody>
</table>
Table 2. Trunk and branching scaffold characteristics such as growth, decay, presence of exudates, fungal activity and vandalism, their description, and the category or unit of measurement recorded.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Description</th>
<th>Categories / units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decay</td>
<td>Any area of the trunk that appeared to be decayed</td>
<td>1. No decay detected</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. Minor areas of decay</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3. Significant areas of decay</td>
</tr>
<tr>
<td>Exudates</td>
<td>Exudates or resin present</td>
<td>Yes/no</td>
</tr>
<tr>
<td>Fungal bodies/ cavities</td>
<td>Present or absent</td>
<td>Yes/no</td>
</tr>
<tr>
<td>Vandalism</td>
<td>Damage caused by human interference</td>
<td>1. No damage detected</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. Suspected damage from mower</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3. Damage from support structure</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4. Suspected vehicle damage</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5. Graffiti</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6. Other human interaction</td>
</tr>
<tr>
<td>Loss of co-dominant leader</td>
<td>Was there a co-dominant leader that is missing</td>
<td>1. No</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. Yes</td>
</tr>
<tr>
<td>Possible reason for missing co-dominant leader</td>
<td></td>
<td>1. Co-dominant leader is dead</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. Co-dominant leader is missing (pruned)</td>
</tr>
<tr>
<td>Epicormic shoots</td>
<td>Presence of lignotuberous or epicormic shoots on the lower or base of the trunk</td>
<td>Yes/no</td>
</tr>
<tr>
<td>Branch loss</td>
<td>The number of missing branches within three diameter classes, (&gt; 20cm, 10-20cm, and less than 10cm) were counted</td>
<td>1. No branches removed</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. One to five branches</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3. Six to ten branches</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4. Greater than ten branches</td>
</tr>
<tr>
<td>Pruning</td>
<td>Apparent pruning noted</td>
<td>1. No pruning apparent</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. Minor pruning (foliage/small branches)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3. Heavy pruning (large portion of canopy)</td>
</tr>
<tr>
<td>Wound repair</td>
<td>Damage to the tree suspected to have occurred in response to pruning</td>
<td>1. Not Applicable – no pruning evident</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. Excellent – no problems detected</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3. Good – some problems, may be due to pruning</td>
</tr>
<tr>
<td>Dead or dying branches or twigs</td>
<td>Proportion of the branches and twigs within the canopy that is dead or dying</td>
<td>1. No death evident.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. &lt; 20%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3. 21-40%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4. 41-60%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5. 61-80%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6. &gt; 81%</td>
</tr>
<tr>
<td>Abnormal foliage</td>
<td>Percentage of foliage that does not appear normal, including abnormal colour or form</td>
<td>1. Foliage appears normal.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. &lt; 20%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3. 21-40%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4. 41-60%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5. 61-80%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6. &gt; 81%</td>
</tr>
<tr>
<td>New growth</td>
<td>Visual assessment of the amount of new growth</td>
<td>1. Significant amounts of new growth</td>
</tr>
<tr>
<td>Distribution in canopy</td>
<td></td>
<td>2. Some new growth evident</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3. No new growth apparent</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1. New growth evenly distributed</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. New growth mostly evenly distributed</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3. New growth unevenly distributed</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4. New growth very uneven and localised</td>
</tr>
</tbody>
</table>
To assess the condition of the main lower order branching scaffold, the number of missing branches and the presence of decay as a response to branch loss or pruning were recorded (Table 2). The numbers of missing branches within three diameter classes (< 10cm, 10-20cm, and > 20cm) were counted. Any damage to or pruning of the trees was noted, as was the proportion of smaller branches and twigs within the canopy that was dead or dying and the percentage of foliage that was either dead or unhealthy (Table 2). The proportion of new growth (a new flush of growth with juvenile foliage and rapid shoot tip extension) was estimated.

A limited assessment of root systems was undertaken, but was confined to those roots that could be seen above-ground within the drip line (Table 3). The number and diameter of exposed roots were recorded. Damage caused by root systems to infrastructure, such as cracking or lifting of footpath paving and roadside curbing was recorded. The raising or lifting of the soil surface around the trunk was noted as it may contribute to infrastructure damage, to maintenance issues such as pedestrian tripping hazards or to difficulties in trimming of turf or undergrowth below the tree. Interactions of tree roots with infrastructure can prove costly in the management of urban street trees.

Table 3. Exposed roots, their description, and the category or unit of measurement recorded for each Eucalyptus leucoxylon tree assessed.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Description</th>
<th>Categories / units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Root exposure</td>
<td>The base of the tree and surrounding soil were observed for exposed roots</td>
<td>1. Roots exposed and girdling</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. Major roots (&gt;10cm) exposed</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3. Minor roots (&lt;10cm) exposed</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4. It is suspected that the ground surface had been raised due to the roots</td>
</tr>
</tbody>
</table>

Results

When yellow gums, *E leucoxylon*, growing as street trees were assessed against the criteria described above, some of the results were as expected. For example, most trees were either red or pink flowered with white flowers as the next most common. Flowering can occur in any month of the year, but in this study there was greatest flowering from August to October. Winter flowering trees can be an important food source for native bird species, such as parrots and for native insects.

The characteristics of trunk and canopy often not only define the value of street trees, but also their success. Single, straight trunks and a rounded spreading and dense canopy are frequently desired in successful street trees. While trees ranged in height from 4.3 m to 26.5 m, nearly 70% of trees were between 5.5 m and 10.9 m, with only 12 trees being less than 5.5 m tall and only four trees being in excess of 18 m in height. About 75% of the trees had the broadly round canopy shape preferred in a street tree and nearly 60% of trees had a canopy density rating of above 60% (Figure 1).

![Figure 1. Frequency (%) of canopy density of 300 yellow gum, Eucalyptus leucoxylon street trees.](image-url)
It will not surprise that most trees were growing in soils that were moderately to highly compacted (Table 4). Soils occurring along major roads and suburban streets are usually, if not always modified, disturbed or turned over. The most common consequence of these construction activities is compacted soil. While a simple field technique was used for determining soil compaction levels, it none-the-less gives an indication of the situations within which yellow gum is growing in urban streets.

**Table 4. Occurrence of different levels of compacted soil surrounding 300 yellow gum, Eucalyptus leucoxylon, street trees.**

<table>
<thead>
<tr>
<th>Soil compaction</th>
<th>Number of trees</th>
<th>Frequency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Impenetrable</td>
<td>5</td>
<td>1.7</td>
</tr>
<tr>
<td>Firm</td>
<td>123</td>
<td>41.0</td>
</tr>
<tr>
<td>Medium</td>
<td>98</td>
<td>32.7</td>
</tr>
<tr>
<td>Soft</td>
<td>40</td>
<td>13.3</td>
</tr>
<tr>
<td>Very Soft</td>
<td>34</td>
<td>11.3</td>
</tr>
</tbody>
</table>

Canopy spread varied from as low as 4 m up to 21 m, but most trees were in the range of 6-11 m in spread (Figure 2). This is a suitable range for urban street trees, where a low traffic suburban street is often about 7m across while busier and major roads can be considerably wider.

**Figure 2. Frequency distribution of canopy diameter (m) of 300 yellow gum, Eucalyptus leucoxylon, street trees.**

Of the trees surveyed, only 22.6% of trees had a dominant stem with the remaining 77.4% had a canopy habit where growth was shared between several large lower order branches. The height above-ground to the first branch ranged from 0 to 5.4 m including pruned trees (Figure 3). Branching occurred at the base of the tree (within 1 m of surface level) in only 3.7% (11) of trees while 80.0% of trees branched between 1 m and 3m. This reflects to some degree, yellow gum’s reputation as a multi-trunked or -stemmed tree.
It is interesting to see that yellow gums planted on streets measured up against many of the criteria established for this research well (Table 5). Nearly 80% of trees had minor or no trunk lean and 83% of the yellow gums had straight trunks, both characteristics that are highly desirable in an urban street tree. The data for live crown ratio showed that over 92% of trees had a ratio in excess of 41%.

Table 5. Trunk and canopy characteristics of 300 yellow gum, *Eucalyptus leucoxylon*, street trees.

<table>
<thead>
<tr>
<th>Trunk form category</th>
<th>Number of trees</th>
<th>Frequency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No lean</td>
<td>97</td>
<td>32.3</td>
</tr>
<tr>
<td>Minor lean</td>
<td>142</td>
<td>47.3</td>
</tr>
<tr>
<td>Major lean</td>
<td>56</td>
<td>18.7</td>
</tr>
<tr>
<td>Extreme lean</td>
<td>5</td>
<td>1.7</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Trunk straightness</th>
<th>Number of trees</th>
<th>Frequency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very straight</td>
<td>105</td>
<td>35.0</td>
</tr>
<tr>
<td>Reasonably straight</td>
<td>143</td>
<td>47.7</td>
</tr>
<tr>
<td>Bark twisted, moderately straight</td>
<td>33</td>
<td>11.0</td>
</tr>
<tr>
<td>Trunk moderately kinked and twisted</td>
<td>14</td>
<td>4.7</td>
</tr>
<tr>
<td>Trunk severely kinked and twisted</td>
<td>5</td>
<td>1.7</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Evenness category</th>
<th>Number of trees</th>
<th>Frequency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Even</td>
<td>144</td>
<td>48.0</td>
</tr>
<tr>
<td>Minor unevenness</td>
<td>89</td>
<td>29.7</td>
</tr>
<tr>
<td>Severely uneven</td>
<td>67</td>
<td>22.3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Branches</th>
<th>Number of trees</th>
<th>Frequency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Even</td>
<td>111</td>
<td>37.0</td>
</tr>
<tr>
<td>Minor unevenness</td>
<td>133</td>
<td>44.3</td>
</tr>
<tr>
<td>Severely uneven</td>
<td>56</td>
<td>18.7</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Live crown ratio</th>
<th>Number of trees</th>
<th>Frequency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;20%</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>21-40%</td>
<td>22</td>
<td>7.4</td>
</tr>
<tr>
<td>41-60%</td>
<td>183</td>
<td>61.2</td>
</tr>
<tr>
<td>61-80%</td>
<td>55</td>
<td>18.4</td>
</tr>
<tr>
<td>&gt; 81%</td>
<td>39</td>
<td>13.0</td>
</tr>
</tbody>
</table>
Street trees must be tolerant of regular, if not frequent, pruning. Of the 300 trees surveyed only 25 showed no evidence of pruning, meaning that 275 (91.7%) had been pruned (Table 6). In general the rating of their response to pruning was from good to excellent.

Table 6. The response to pruning of 300 yellow gum, Eucalyptus leucoxylon, street trees.

<table>
<thead>
<tr>
<th>Response to pruning</th>
<th>Number of trees</th>
<th>Frequency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No pruning evident</td>
<td>25</td>
<td>8.3</td>
</tr>
<tr>
<td>Excellent</td>
<td>129</td>
<td>43.0</td>
</tr>
<tr>
<td>Good</td>
<td>99</td>
<td>33.0</td>
</tr>
<tr>
<td>Poor</td>
<td>47</td>
<td>15.7</td>
</tr>
</tbody>
</table>

Discussion

The criteria presented here and the lists and tables provided in (Moore and Chandler 2023) could be applied to street trees generally or modified by local government and other urban forest management agencies not only to characterise suitable species for street tree use but also to assess local street tree performance. They could be of value in assessing candidate species for future street tree planting under changed climate conditions. Rather than using anecdotal assessments of street tree performance, criteria are established and trees are then assessed against these criteria in a measureable and repeatable way.

Selecting high quality planting stock is an essential pre-requisite for the successful establishment, growth and efficient maintenance of street trees. Yellow gum, E. leucoxylon, clearly has the potential to be a significant and more widely planted street tree, not just in Australia, but elsewhere where it has been grown successfully or where future climatic conditions would be conducive to its growth. Specimens have canopy and trunk characteristics such as straight trunks and rounded spreading and dense canopies. Most specimens are of suitable height for urban use, but care must be taken to propagate and grow trees with the desired characteristics as poor quality seed sources could undermine the value of planting.

Over 75% of trees assessed showed a good or excellent response to pruning. Given the large sample size, this is a good indication that yellow gum copes well with regular pruning, as indicated by its capacity to seal off, produce woundwood and grow over pruning cuts. Many of the yellow gum specimens were growing under or near powerlines and their ability to cope with poor powerline pruning could have a profound effect on their longevity and in any thorough cost:benefit analysis on their value in comparison to other street tree species. Typical of most eucalypts, E. leucoxylon trees showed strong epicormic shoot response to pruning and branch loss with 83% of pruned trees initiating epicormic growth (Moore 2021). The species can also rapidly regenerate from lignotuberous shoots after major trunk damage (Moore 2015), allowing a rapid renewal of the canopy and restoration of foliage density, demonstrating an ongoing capacity for carbon sequestration. Generally high crown ratios with 92% of trees with a ratio above 41%, indicate that E. leucoxylon trees provide valuable shade in a compact canopy. This growth habit and the shade provided can reduce the UHI effect and enhance the species’ role in the city’s capacity to respond to a warming climate.

It will not surprise any regular attendees of TREENET conferences that most of the trees assessed were growing in moderately to highly compacted soils. Urban soils, especially those along roads sides are often compacted during construction but despite these growing conditions, many yellow gums established and continued to grow well. They are hardy trees capable of withstanding the stresses of urban environments. The successful growth of urban trees with good canopy spread and density will be crucial to establishing adequate urban canopy cover that may assist in mitigating urban heat island effects as climates warm.

The most commonly planted subspecies of yellow gum is E. leucoxylon ssp megalocarpa and this was evident in this study as almost all of the trees assessed were likely to be ssp megalocarpa. Nicolle (2002) suggested that E. leucoxylon ssp petiolaris was well suited to street tree planting due to its size, growth rate and tolerance of saline soils among other preferred street tree characteristics. Similar research to that reported here but on E.
leucoxylon ssp petiolaris would seem worthwhile, but it is not easily distinguished from other subspecies when mature.

While there are considerable data in this study of yellow gum, *E. leucoxylon*, there is still much that remains unknown. There are little, if any, data on the age classes of yellow gums planted as street trees or on their likely useful life expectancy. It would be useful to know both in determining the real value of yellow box as street trees in the long term. Given the preference for street trees to have single trunks and remain branch free to a height that suits pedestrian traffic and sight lines for vehicles, it would be worthwhile knowing the propensity for multiple stems and low branching in yellow gum. This study provides some relevant data on both aspects, but for a population of trees that has been closely managed and regularly pruned.

**Conclusion**

Yellow gum, *Eucalyptus leucoxylon*, is a widely planted street tree species across Melbourne, but also more broadly in parts of south-eastern Australia and extending into Queensland and parts of Western Australia. This study shows it to be a successful and valuable street tree that exhibits many of the attributes demanded of an urban street tree. There is considerable variability shown within its phenotype, but careful selection and propagation from superior specimens could improve its performance as a street tree against the criteria suggested. These criteria could also be applied to other eucalypt and related species in a way that could guide the selection of species appropriate for urban street tree use and to assess the success and performance of trees once planted. Yellow gum provides many of the environmental services both demanded and expected of street trees as climate changes. It has been planted well beyond its natural range and performed well, suggesting that it may be considered a climate change ready species. It is also possible that *Eucalyptus leucoxylon* may be a suitable urban street tree in other parts of the world as climates change and new planting options are considered.

**Acknowledgements**

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ENGINEERED SPACES FOR TREES IN DUBBO REGIONAL COUNCIL – MODIFIED STOCKHOLM TREE PLANTING METHOD

Ian McAlister
Dubbo Regional Council

Abstract

As Australia’s climate warms our cities and towns, councils face an increasing array of challenges in mitigating urban heat and its impact on communities and biodiversity. Local governments are under additional pressure to expand tree canopy cover to help improve resilience against projected rises in temperature. While councils understand the need for more trees, further densification of urban centers through smaller lot sizes and infill development counters their ability to make significant gains. Large residences on these smaller allotments reduce tree planting opportunities and the ability of the private urban forest to contribute to canopy cover. In many new subdivisions the width of road reserves has been reduced, including the verge that previously allowed large trees to be planted. Underground utilities and services further reduce planting opportunities. Where majestic trees once lined and shaded streets, councils are now forced to plant smaller and narrower species which reduces shading and results in more heat being absorbed. Not only does this reduce the comfort level of residents but it has a financial impact on councils through reduced life of asphaltic road seals. Loss of tree-lined streets also impacts habitat and biodiversity links needed to support wildlife. These challenges place more pressure on the public urban forest to achieve the desired greener, shadier and cooler urban centers. To meet these challenges Dubbo Regional Council has constructed a variety of tree planting pits, including root vaults designed to allow growth under roads and footpaths. This paper reports tree growth in vaults constructed using structural cells and a modified Stockholm Method. A street beautification project completed in the early 1990s is also presented as a case study. In this project trees were planted into pits with vastly different volumes of soil. Thirty years on, the growth and the development of the trees serves to reinforce the need for adequate soil volume to be provided for urban trees.

Introduction

Dubbo Regional Council is located in central New South Wales, covers 7,563 km² and its population of 51,050 is based largely in the City of Dubbo (42,500) and Wellington (4,500). Dubbo’s climate is characterised by hot summers and cool winters, with winter night temperatures dropping to well below freezing. While Dubbo’s reported mean maximum temperature for January is 33°C, consecutive days over 35°C and over 40°C are increasingly common. AdaptNSW (2023) identified that the region experiences 20 – 30 hot days (>35°C) every year, but in 2018 temperatures exceeded 35°C and 40°C on 52 and 9 days respectively. 2019 temperatures exceeded 35°C and 40°C on 67 and 16 times respectively. In contrast, 2020, 2021, and 2022 saw a significant reduction of days over 35°C and 40°C as a result of the prolonged La Nina weather pattern. Annual rainfall between 2018 and 2022 inclusive was 311, 211, 573, 564 and 863mm. While the La Nina provided some respite in recent years it is predicted that global temperature records will be broken within the next five years (WMO 2023). A warming trend is consistent with climate change projections from the NSW and ACT Regional Climate Modelling (NARCliM) that predicts that temperatures will rise by 0.7°C between 2020 and 2039) and by 2.1°C by 2079 compared with 1990 – 2009 average (NSW Govt. 2023).

Projected global mean surface temperature has been predicted to rise this century due to carbon emissions by between 2°C and more than 5°C under various emission scenarios (Arias et al. 2021). In these scenarios the frequency and intensity of heat waves and drought conditions are anticipated to increase. These climatic changes and particularly the increased frequency of extremes add to the challenges of selecting and establishing tree species in urban environments. As an example, Red ironbark (Eucalyptus sideroxylon) occurs naturally in the Brigalow Belt South Bioregion which includes Dubbo, and it is considered to be extremely drought and heat tolerant. The Climate Assessment Tool (v1), an assessment tool developed by Botanic Gardens Conservation International (Climate Change Alliance of Botanic Gardens, 2023), is one tool available to help forecast species’ likely suitability for a given location under changing climate scenarios.
Under Dubbo’s existing climatic conditions with a mean temperature of 17°C, *Eucalyptus sideroxylon* thrives within its natural distribution. Due to its local suitability, *E. sideroxylon* has been widely planted in urban settings in Dubbo with a high degree of confidence that they will establish well and thrive. The climate assessment tool indicates that an increase in mean temperature of 2°C will make conditions at Dubbo’s location similar to warmer botanic gardens in which it currently grows. The tool does show that the species is known to occur in urban situations at this temperature. However, under this scenario an urban tree manager may begin to consider whether to use the species in street plantings or to investigate alternatives, but may be more likely to continue to plant it in parkland situations. A 5°C increase in mean temperature would place Dubbo at the upper limit of temperature known for the species, including in urban environments. A tree manager at Dubbo may, therefore, consider planting *E. sideroxylon* to be unwise in traditional street and park planting approaches under a 5°C mean temperature increase scenario and may look for alternative species or cultural techniques. At higher temperatures *E. sideroxylon* might be unlikely to survive without significant intervention through urban design or support.

While this tool has been developed to assist botanic gardens’ managers to transition their living collections for resilience in the changing climate, it does provide some information to help urban tree managers to consider and when revising urban planting palettes in preparation for warmer and drier long-term conditions. On a broader landscape perspective (i.e. non-urban) it also identifies that there is potentially significant floristic and faunal changes that may result as temperatures increase, but the level at which the environment can buffer these predicted changes is not known. It does not, however, consider that plantings of tree species exist in urban centres in private gardens, streets and parks, which are beyond the climatic ranges represented by botanic gardens collections; these plantings demonstrate potentially greater suitability for urban applications than that indicated by botanic gardens data.

Increasing shading over road surfaces by as little as 20% can effectively reduce ambient temperatures by 3 - 4°C (McPherson & Sacamano, 1993), and reduce the risk of UV radiation exposure by up to 75% (Parsons et al. 1998). Increased tree canopies within the urban landscape can also provide significant infrastructure savings to councils and their communities, including reducing the number of reseals required within a given timeframe and extending the life expectancy of road pavements (McPherson & Muchnick 2005), and reducing and delaying stormwater peak flows and nutrients loading to water ways (Xiao et al. 1998). To achieve these benefits for residents, Dubbo Regional Council is investigating engineering approaches to better establish and nurture trees, to strengthen urban forest resilience in the region and provide a more comfortable and safer environment for the community in the changing climate.

**Spaces for trees: comparing engineering approaches**

Since 2011 Dubbo Regional Council has been trialing different approaches for constructing tree planting sites to identify cost-effective approaches suited to local social and environmental constraints and conditions. Initial approaches used up to 2011 were designed along traditional lines with the focus on excluding roots from soil that supported infrastructure, by containing them within a barrier. Limitations of this approach led to consideration of methods to increase soil volumes, which involved the testing of structural cells, the Stockholm Method (Figure 1).

The concrete ring design was used in response to concerns regarding roots potentially damaging road pavement. This low-cost approach allayed engineer’s concerns that roots might otherwise impact the road pavement and it provided a slight increase in soil volume and quality compared with the previous practice of planting directly into the road base. The benefits of this approach were limited by the small volume of quality soil however, and it was only really suitable for small species as Crepe myrtle (*Lagerstroemia indica*).

In 2013 structural cells were installed under the road pavement to create root vaults as part of a major civil infrastructure project undertaken by Council. Series 5 and 6 Stratacell™ have been used in various projects, with Series 5 shown in Figure 1. This approach has and continues to provide impressive results in terms of the rate of growth and the health of the trees.
In 2015 Council commenced trialing the Stockholm Method. This method was developed by Johan Östberg and utilises a rock matrix with biochar in the voids between the rocks. A 250 – 300 mm thick layer of rock is placed in an excavated pit and lightly compacted to ensure that the rock matrix is interlocked. Further layers are added to achieve the desired depth of the pit. Biochar is then washed into the voids and it is the biochar that forms the growing medium (Alvem et al., 2009). As the tree grows, new biomass is produced within the biochar through the growth and death of fine and very fine roots and associated micro-organisms, with the nutrients that are released then largely taken up to nourish further growth of the tree.

In 2016 and after consulting with ENSPEC Environment and Risk a modification was made to the method: a soil and compost component was added to the mix. The revised blend was comprised of 50% rock (250 – 300 mm stones), 35% soil/compost and 15% biochar. This blend provides a high degree of structural integrity to the root vault, with the soil/compost and biochar providing a growing medium with a readily available nutrient bank from time of construction. As the tree develops its root structure, additional biomass and nutrients within the matrix are developed, turned over and renewed. A major benefit to Council of this modified method is its cost effectiveness, as it utilises rock which is a waste product from a council sub-division, compost from Council’s own composting system, and less time and labour are required for installation. Replacement of some of the biochar with the soil/compost mix delivers further significant savings. An updated version of the City of Stockholm’s manual similarly notes the use of a blend of nutritionally enriched biochar and compost amongst the stone (Embrén and Alvem, 2017).

After trialling a number of approaches, Dubbo Regional Council has now settled on a preferred root vault design for planting trees in streetscapes using the Modified Stockholm Approach. The volume of the root vault is determined by the formula \( V = \pi r^2 \times 0.6 \), where \( r \) is the radius of the mature canopy cover of the tree species chosen. The 0.6 figure accounts for the fact that the majority of a tree’s roots typically occur in the top 0.6 m of soil, although deeper root penetration can be achieved through the addition of air vents through the rock matrix.

An open-ended concrete “box” is installed, which protects the road pavement and encourages the roots into the surrounding rock matrix. The bottom of this box is installed within the rock matrix, with the matrix extending out beyond the box. To limit the potential of root intrusion into the sub-base of the road a geo-fabric is installed at the interface between the rock matrix and the road. The box’s straight edges are favoured by engineers and construction personnel it makes compaction around the tree pit easier to achieve, thus reducing the potential for future settlement of the road pavement.

Grates are made to fit the top of the tree ‘box’; a local metal fabricator cuts them from plate steel using a plasma cutter and then they are galvanised (Figure 2). The size of the box and grate can be varied to suit specific site and tree species requirements. The grate enables a degree of passive water capture of the road and further supplementary watering using a water truck as required. To assist air and water movement slotted PVC pipes
are inserted into the rock matrix at varying depths. Drainage of the structural soil mix may also be required, depending on site characteristics such as catchment size and imperviousness, soil type, and surrounding land uses including vegetation.

Figure 2. A tree pit constructed using the Modified Stockholm Method, Dubbo Regional Council’s ‘box’ design and a galvanised steel grate.

To investigate the impact of the different planting methodologies Dubbo Regional Council began a trial in December 2016 in collaboration with Citygreen. The trial was established to examine root development and plant growth (height, calliper and condition) over a 10-year timeframe. As the trial requires access to the tree roots at the end of the trial the trees were planted in 6 skip bins of 9 m³ each (Figure 3). The bins were installed above ground, with soil mounded around them to shield the bins from excessive heat and so mimic more-natural growing conditions. Each bin contained a different soil treatment and one Silky oak (*Grevillea robusta*) tree was planted into each bin. The six soil treatments are:
Trees were planted from 200 litre containers on 2nd December 2016. An irrigation system was installed to water the trees and no additional fertiliser has been applied. Tree height and diameter at breast height (DBH) were measured at the time of planting and on 21 December 2019 (36 months), 16th April 2021 (52 months) and 16th May 2023 (77 months) (Figures 4 and 5). During the 77 months of growth from 2 December 2016 the height of the trees increased by between 82% and 109% in control soils and treatments and the DBH increased by between 86% and 213% (Table 1). Initial measurements revealed greater height increase in the Stratcell treatments and controls than in the Stockholm method treatments, but the trees in the Stockholm treatments grew most rapidly in the last 24 months.

After 77 months the DBH had increased more in both controls and the Dubbo-modified Stockholm treatment than in either of the Stratcell treatments. The density of the foliage of the trees appeared to vary when height and DBH measurements were taken in May 2023, with the tree in the Dubbo Regional Council-modified Stockholm treatment appearing to have the greatest foliage density (Figure 7). The health of the tree in the DRC-modified Stockholm treatment is considered best overall after 77 months in-situ growth. When measured in May 2023 all trees appeared in average to good health with no evidence of pests or disease. The trial still has another 43 months to run, after which the pits will be disassembled and the roots of each of the trees will be examined.
Figure 4. Grevillea robusta tree height increase in control and treatments over 72 months since planting date.

Figure 5. Grevillea robusta tree trunk diameter at breast height (DBH) increase in control and treatments over 72 months since planting date.
Table 1. Change in height and Diameter at Breast height (DBH) over 76 months since the commencement of the trial

<table>
<thead>
<tr>
<th>Bin no.</th>
<th>Treatment</th>
<th>DBH increase (%)</th>
<th>Height increase (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Control 1 natural soil</td>
<td>139</td>
<td>109</td>
</tr>
<tr>
<td>2</td>
<td>Control 2 native soil mix</td>
<td>213</td>
<td>101</td>
</tr>
<tr>
<td>3</td>
<td>Stockholm (DRC)</td>
<td>186</td>
<td>94</td>
</tr>
<tr>
<td>4</td>
<td>Stockholm (trad)</td>
<td>86</td>
<td>82</td>
</tr>
<tr>
<td>5</td>
<td>Series 5 Stratacell</td>
<td>122</td>
<td>105</td>
</tr>
<tr>
<td>6</td>
<td>Series 6 Stratacell</td>
<td>94</td>
<td>105</td>
</tr>
</tbody>
</table>

Figure 7. Grevillea robusta trees in controls and each treatment photographed after 77 months growth.
Macquarie Street, a case study

Dubbo’s Macquarie Street serves as a practical, real-life example of the importance of providing urban trees with an adequate volume of quality soil. In the early 1990s Dubbo Regional Council undertook a major beautification of Macquarie Street. Prior to this Macquarie Street was largely devoid of trees, with shop awnings providing shade on verges and footpaths.

Two tree species were chosen for this project: Hackberry (*Celtis occidentalis*) and European nettle tree (*Celtis australis*). Three different planting environments were created by the engineering design. Some trees were planted on traffic roundabouts and in relatively large garden beds on street corners near the roundabouts, others were planted in tree pits along footpaths on both sides of the street, and trees were planted in a narrow median island along the centre of the street.

The trees in traffic roundabouts and garden beds grew in soil with mulched surface areas of 90 m² to 100 m²; these gardens had quality soil to approximately 1 m deep. The roundabouts are surrounded by compacted road base materials and sealed asphalt road surfaces. The trees planted on road verges grow in tree pits with a surface area of 1.5 m² surrounded by brick-paved footpaths laid on a concrete base. Footpaths contain a variable array of underground utilities mains and service connections. Commercial premises built to the adjacent property boundary are typically on substantial footings. The kerb and road adjacent to the footpath were built on compacted base and subgrade. Trees on the median island were planted in 0.8 m² tree pits with a maximum soil depth of 0.6 m. The median island is 0.7 m wide between sealed asphalt road surfaces. Trees in these different planting sites are visible in Figures 8 and 9.

Figure 8. Macquarie Street, Dubbo, looking South from Talbragar Street; trees growing in the median island appear consistently smaller than those growing in larger tree pits on the road verges.
Street trees in central Dubbo were independently audited in 2012. In total 49 trees were assessed in Macquarie Street: 43 *C. occidentalis* and 6 *C. australis*. Diameter at breast height was measured and recorded during the assessment but tree height and structure were not, due to past pruning of the canopies for traffic and building clearances. A follow-up audit in 2023 measured DBH so the growth of trees in the different growing sites over the intervening 11 years could be compared.

Comparison of the increase in DBH of *Celtis australis* trees growing in larger soil volumes on roundabouts (n = 2) with those in the smaller soil volume in the median (n = 4) through a two-tailed t-test revealed the difference was significant (p = 0.02) (Table 2).

Table 2. DBH increase of *Celtis australis* growing in road median islands between 2012 and 2023 was less than for trees on traffic roundabouts and garden beds with larger soil volume.

<table>
<thead>
<tr>
<th></th>
<th>roundabouts &amp; garden beds</th>
<th>medians</th>
</tr>
</thead>
<tbody>
<tr>
<td>DBH increase (%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>minimum</td>
<td>51</td>
<td>19</td>
</tr>
<tr>
<td>maximum</td>
<td>70</td>
<td>38</td>
</tr>
<tr>
<td>mean DBH increase (%)</td>
<td>30</td>
<td>61</td>
</tr>
<tr>
<td>DBH increase range (%)</td>
<td>19</td>
<td>19</td>
</tr>
</tbody>
</table>

The two-tailed t-test was used to compare growth in DBH of *Celtis occidentalis* in the different sites. Trees growing in roundabouts and large garden beds (n = 7) were compared with those in medians (n = 5); trees growing in footpaths (n = 31) were compared with those in medians, and the increase in DBH of trees growing
in roundabouts and large garden beds was compared with growth of the trees in footpaths. The difference between trees growing in medians and those in roundabouts and large beds was significant (p = 0.02). The difference in growth between trees in the footpath and those in the median was also significant (p = 0.04). The test revealed no difference between trees growing on footpath tree pits and those in the larger soil volumes (p = 0.21)(Table 3).

Table 3. Growth of Celtis occidentalis between 2012 and 2023 in traffic roundabouts and garden beds, footpaths, and medians.

<table>
<thead>
<tr>
<th></th>
<th>roundabouts &amp; garden beds</th>
<th>footpaths</th>
<th>medians</th>
</tr>
</thead>
<tbody>
<tr>
<td>DBH increase (%)</td>
<td>25</td>
<td>6</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>DBH increase (maximum)</td>
<td>57</td>
<td>60</td>
</tr>
<tr>
<td>mean DBH increase (%)</td>
<td>36</td>
<td>31</td>
<td>22</td>
</tr>
<tr>
<td>DBH increase range (%)</td>
<td>32</td>
<td>54</td>
<td>13</td>
</tr>
</tbody>
</table>

As expected the results show that the trees with access to a larger volume of quality soil performed better. The trees in the roundabouts and adjacent large garden beds had a greater volume to accommodate roots and a greater soil surface area to support rainfall infiltration and diffusion of gases. For the trees growing in the footpath, water infiltration and gas diffusion were restricted by the impermeable paved surface over its concrete base, but not as much as for the trees in the smaller pits in the medians. Root development in some median trees has been observed to be minimal, with several having been wind-thrown in recent years. It was surprising that the analysis did not reveal a difference of any significance in growth between the trees in the footpaths and roundabouts.

**Conclusion**

Dubbo Regional Council remains proactive in designing, trialling and mainstreaming urban tree planting and establishment methodologies with the intent of increasing our urban forest’s resilience against the impacts of urbanization and climate change. It is important to trial new engineering approaches locally, to identify methods that work best for any given situation. Economic considerations often guide decision making on new projects and on investigations such as those described in this paper, and trials can be helpful in providing the necessary information to balance benefits and costs. The changing climate means the goal posts are constantly moving so there is always need for more trials and over longer timeframes, but the projects described in this paper show that it is possible to improve urban forest resilience through appropriate engineering design and construction for trees.

**References**


ENGINEERED SPACE FOR TREES IN MOUNT BARKER DISTRICT COUNCIL

Shraddha Dhungel¹, Chris Lawry¹, Tim Johnson²
¹Mount Barker District Council, ²Treenet Inc.

Abstract

In 2010 approximately 1300 hectares of rural land in Mount Barker District Council was rezoned by the state government for residential development. Due to its attractive hills location and proximity to Adelaide the district’s population is now growing at 3.5% per year, nearly 7 times the rate of metropolitan Adelaide, and it will become South Australia’s second largest city within a decade. Growth has increased pressure on existing infrastructure across Mt Barker and the district’s other towns, and urbanisation has encroached on large, remnant native trees. Successfully preserving and planting trees during development and infrastructure renewal and upgrading projects demands best practice. This paper presents examples of planning, engineering and urban forestry practices that have allowed mature trees to be retained and new trees to be planted through these development and renewal processes. Case studies presented include road alignment to retain remnant trees, public open space provision to preserve trees, street tree planting for traffic calming, and stormwater detention basin design to preserve existing trees and support additional planting. Case studies demonstrating engineering best practice for trees include the use of structural soil, continuous tree trenches, and retrofitting of trial species in traffic control roundabouts.

Introduction

Urban development is changing in response to human, environmental and economic factors, scientific research and technological progress. The scale of urbanisation across the globe threatens ecological systems and services (Sidemo-Holm et al. 2022; Theodorou 2022; Kii 2016), so greener, nature-based urban development options are being applied to support sustainability and biodiversity conservation (Chan & Chan 2022; Pereira & Baró 2022). The pace of this greener evolution continues to increase due to growing awareness of the essential need for human connection with nature in cities (Martin & Almas, 2022; Mills, 2022) and increasing community angst with the loss of urban and peri-urban nature such as trees and habitat to urban development.

The development and adoption of new standards for urban design and civil engineering are supporting the transition to greener and more liveable cities and towns. To ‘provide guidance for the commissioning, design, planning, approval, construction, maintenance and operation of urban green infrastructure elements, systems and networks’ Standards Australia has recently released a planning and decision framework (Standards Australia 2023). This planning and decision framework builds upon previously released Australian Standards developed since the 1996 publication of AS4373, since revised, which specifically guide the protection of existing trees during development, nursery production of new trees, and tree pruning, with which all works in Australia should aim to comply with as a minimum:

- AS4373 - 2007 Pruning of amenity trees
- AS4970 - 2009 Protection of trees on development sites
- AS2303 - 2018 Tree stock for landscape use

As with any Australian Standard, compliance with arboriculture and urban forestry-related standards requires understanding of theory and practical matters relating to the materials, tools and processes involved in the project at hand. As in any profession, this understanding comes through appropriate training and experience. Success, therefore, relies on the involvement of all relevant professions in the different stages of urban development and civil works projects. If these projects involve trees - either the retention, protection and ongoing management of mature trees or procurement, installation, establishment and ongoing management of new trees – then a project arborist must be appointed at the concept scoping stage and involved for the duration of the project and beyond. This approach has been fundamental to the success of the case studies presented in this paper.
Concurrent with the development of arboriculture-related standards, engineering practices to support trees have also progressed including the use of structural soils (Grabosky & Bassuk 2016; Day & Dickinson, 2008), structural cells (Ow & Ghosh, 2017). Structural soils are designed to overcome the growth-limiting effects of soil compaction (Zisa, Halverson & Stout, 1980; Smith, May & Moore, 2001), by providing uncompacted soil to support root growth in the voids in a consolidated stone matrix which bears surface pavement loads. Structural cells bear surface loads via their structural members through uncompacted root-zone soil to a foundation beneath the root zone. In situations where site soil is highly compacted or otherwise unsuitable for sustaining the chosen tree species to maturity under the local conditions (Haege & Leake, 2014), structural soil or cells can make contribute to achieving the necessary soil volume.

These approaches are now well developed and understood but their application is increasing only slowly. While their use is not yet mainstream, community concern with environmental issues is encouraging some leading local government authorities to establish trials. Local government trials have many benefits but two that are of direct benefit and highly valuable to the council involved are (1) the ability to examine the effectiveness (including life cycle cost effectiveness) of alternative treatments under local conditions and (2) staff exposure to novel methods for professional development and education purposes. The learnings that come from trials will inform future planning and project decisions and likely accelerate local mainstreaming of innovative approaches. Progress always comes back to making informed decisions based on the latest, most complete knowledge, rather than business as usual approaches based on outdated knowledge.

This paper presents case studies where these and other innovative practices have been used in urban settings to establish new trees and to retain, protect and nurture mature trees on development sites. This paper’s purpose is not to interpret or reiterate the horticultural or engineering science underlying these practices, but to demonstrate that they are realistic design and construction options that are available, are in current use, and should be considered for further use in appropriate locations. It seems inevitable that such options will be utilised more in the future as they become more cost-effective, familiarity with them increases, relevant standards are developed and increasing community awareness of environmental issues drives demand.

Case Studies

Case study 1: Tree retention in a master-planned greenfield development

The Springlake multi-stage residential housing development in the Mount Barker District Council presented both the need and an ideal opportunity to apply best practice in protecting existing trees. This greenfield development site on the land of the Peramangk people had been used for grazing and cropping since European colonisation. Many mature individual trees and stands remained from the site’s pre-European River red gum/South Australian blue gum (Eucalyptus camaldulensis/Eucalyptus leucoxylon ssp. leucoxylon) woodland vegetation, including roadside vegetation at the periphery. Trees with high retention value were identified early in the development planning process and designs were developed that considered tree protection needs.

Many high value trees were retained by designing community green space around them. Trees were protected in a major linear park aligned along the natural drainage line, others were retained in allotment-scale pocket parks, and others were protected by aligning streets to include them so they remained under council’s care (Figure 1). Pocket parks for tree protection were designed to include the tree to the canopy dripline or beyond, to reduce the likelihood of impacts arising from lopping of limbs overhanging adjoining properties; parks of this size also ensured adequate root zone protection. Trees retained in streets were protected by increasing the setback of nearby properties, by informing and guiding site development in tree protection zones on private property through development assessment and approval processes, and through tree-sensitive engineering practices in the streetscape itself. Some of these methods are described in more detail in the following case studies.
Figure 1. The Springlake development protected remnant trees and stands a linear park, pocket parks and through appropriate road alignment and engineering.

Case study 1A: Red Gum Crescent: engineered root zone protection

Three mature River red gum trees with less than 20 m between their canopy driplines would have required large allotments to support reasonable development if tree retention had been required on private property. Instead, novel road design and engineering were used to provide safe access around the trees at the intersection of Springview and Red Gum Terraces (Figure 2). Designing the trees into the public realm kept them in community ownership, reduced the impact on the number of residential allotments, and allowed for ongoing tree protection and management by the council. Road construction at this site was completed in 2016.

To protect the largest tree a roundabout was designed to accommodate its root zone and canopy. Construction of the circular roundabout was completed with no impacts within a tree protection zone of 15 m radius, the maximum radius specified in Australian Standard 4790-2009 Protection of trees on development sites. This tree protection zone eliminated any need for tree pruning, with foliage retained to near ground level (Figure 3).

The critical root zones of the two River red gum trees on the verges near the intersection extend beneath the road. To maintain soil conditions beneath the road suitable for root growth a novel road design was used. The pre-existing ground levels were left unaltered, soil was not compacted during construction but invariably along the road alignments had received a degree of unintended compaction through heavy vehicle access. The surface of these sites was de-compacted by raking with the tynes of an excavator bucket to 100 mm deep prior to laying geotextile and a 200 mm deep layer of 40 mm ballast. The rock ballast was rolled and rattled to ensure interlock, which would have resulted in some subgrade compaction but to a lesser extent than conventional roadbuilding techniques. The reinforced concrete road surface was poured above the ballast (Figure 4) across the root zones of trees that were retained (Figure 5). The ballast base layer design provides structural integrity on low-strength
(uncompacted) subgrade while supporting soil ventilation, with the added benefit of deterring shallow root growth (Coder 1998; Gilman 2006; Johnson et al. 2019), which could potentially damage the road surface.

![Figure 2. Mature trees were retained through novel design and engineering (image: Google Maps).](image1)

![Figure 3. Protection of tree root zone and canopy space are critical to long-term tree retention (images: T Johnson).](image2)

Installation of utilities and services in tree protection zones was minimized and utilities were laid outside of critical root zones where practical. Within critical root zones trenching was supervised to ensure minimal impact on trees. No roots greater than 25 mm in diameter were removed without prior approval of the project arborist. Roots greater than 50 mm diameter were treated as a live utility service.

The mulched areas beneath the trees are low maintenance, will improve soil organic content over time, and are available for future companion planting to maintain tree health and conserve biodiversity. Increasing soil carbon in the road reserve through mulching and companion planting has been shown to improve soil microbial diversity over time (Mills 2022), which has direct benefits for community and environmental health. Narrowing of the carriageway and designing its alignment to increase separation from the tree also increased separation of pedestrians from the carriageway (Figure 5), thereby improving community safety.
Case study 1B: Wind Row Avenue: divided residential street
Road engineering allows some flexibility that can help to preserve existing trees as demonstrated in the previous case study, but greater creativity in design provides further opportunities as demonstrated in Wind Row Avenue. Not all existing trees warrant protection, including declared pest species, specimens that are structurally flawed, and trees that are diseased and untreatable, for example. An arborist’s survey determined that near the intersection Wind Row Avenue and Honeysuckle Way the trees with the highest retention value were numbers 78, 79 and 83 in Figure 6, and so plans were developed to protect these. Removal of trees 75, 76, 77, 80, 81 and
82, being mainly smaller trees that were more readily replaced, supported better protection of the larger, more highly valued specimens. Using a 40 mm ballast road base on uncompacted subgrade in a divided road supported retention of tree 78 in a widened median island. Reducing Honeysuckle Way to a driveway link at the intersection allowed tree 79 to be retained. Tree 83 was protected using the method shown in the previous case study.

Interaction with roots during utilities installation is inevitable in cases such as Wind Row Avenue where critical root zones cover much of the road reserve. As in case study 1A trenching was supervised to ensure minimal impact on trees, non-destructive excavation techniques were used for root investigations, to the depth of the deepest services to be installed in tree protection zones, and no roots more than 25 mm in diameter were removed without approval of the project arborist. The typical location of the root investigation trench was beyond the structural root zone and near the proposed edge of the road infrastructure (Figure 7). These iconic trees now dominate the skyline and provide ongoing amenity and ecosystem services (Figure 8).
Figure 7. Root exploration trenches were excavated to the depth of the deepest service (image: Greenhill).

Case study 1C: Bremer Street driveway Links
One large River red gum and one SA bleu gum in what is now Bremer Street were identified as having very high retention value due to their size, long life expectancy and habitat values including abundant hollows of various sizes. Retaining these trees required a multi-faceted approach including revision of adjacent allotment sizes, boundary alignment, and road design and construction. Broader allotments near the trees allowed for increased set-back of dwellings to reduce issues resulting from perception of risk related to canopy overhang. Boundaries between adjacent properties were aligned so that driveways and utilities could be located on the opposite sides of the allotment to the trees.

Figure 8. Wind Row Avenue divided road tree protection solution (photograph: C Lawry).
Carriageway width was reduced to driveway links near the trees and these were located as far from the trees as possible, toward the opposite side of the road reserve to maximise undisturbed root zone and tree-protection clearance (Figure 9). Driveway links were constructed of concrete above a layer of 40 mm ballast on uncompacted subgrade (Figure 10). Specifications required inspection of the ballast layer prior to pouring of concrete and exclusion of plant and equipment from the root zone prior to and during construction. The driveway links with mature trees and landscaped understory plantings are attractive features in the street and they function as traffic calming devices (Figure 11).

![Figure 9](image.png)

**Figure 9.** Tree retention and root zone protection achieved through modification of allotment size, replacement of road carriageway with driveway links, and novel road design (image: Google Maps)

![Figure 10](image.png)

**Figure 10.** Bremer Street driveway link design cross section (image: Greenhill)
Case study 1D: Karra Circuit park

Where adequate space to preserve a tree’s canopy and root system is available and it is possible to prevent compaction, contamination and any change to surface hydrology, the best way to protect remnant trees is to leave them totally undisturbed. Designing pocket parks into greenfield developments is one way to achieve this, as in Karra Circuit (Figure 12). The pocket park fully contains the canopy of two remnant trees and, whilst the roots may extend beneath what has been developed as footpath, road and adjoining residential allotments, any impact is minimal and trees are dynamic and will soon adapt to make use of alternative accessible soil volume. The Karra Circuit pocket park is a valuable addition to local open space as it adjoins the linear park to the south.
and extends habitat and canopy cover toward other remnant trees to the northwest and Martin Road. The location of these remnant iconic habitat trees should guide planning for greenway and habitat creation using optimal street tree cover and companion planting with understory species. Capture and biofiltration of stormwater could also be considered as part of a wholistic future design to further enhance biodiversity conservation and human and environmental health and wellbeing.

Figure 12. Preservation of high value remnant trees can be best achieved through land acquisition; such action is readily justified when connectivity, biodiversity and human, community and environmental health and wellbeing are considered (image: Google Maps)

Case study 2: Roadside tree trench, Old Princes Highway, Nairne, SA.
The Old Princes Highway through Nairne with its wide carriageway, narrow verges, deteriorating pavements and steep grade toward the northeast presented challenges to infrastructure managers responsible for asset renewal. Road and footpath renewal were essential, so council’s engineers took the opportunity to address difficulties with drainage and levels which impeded access between the road and commercial premises to the north-east. The crossfall and proximity of the adjacent premises dictated the solution also had to incorporate a structural retaining wall component. With only 3.8 metres between the edge of the carriageway and the premises to accommodate the footpath, some might have been tempted to reduce or omit tree planting to accommodate underground utilities, verandas, and the retaining structure needed to deal with the crossfall. Council integrated trees into the design solution to improve amenity, improve pedestrian access (Figure 13, left) and to add value to the commercial space through increased alfresco dining (Figure 13, right). To achieve this a design solution was developed that incorporated a structural soil (Figure 14).
Figure 13. Structural soil supported improved pedestrian accessibility and increased soil volume for roots (images: T Johnson 2023)

Figure 14. Tree trenches with structural soil increased root volume beneath tree pits and footpaths. The trench shown above is indicative; 16.6 m in length it contained 12.7 cubic metres of structural soil.

The structural soil was comprised of 80 – 160 mm crushed rock. Minimal soil was used in the voids between the stones to retain much of the void volume for air and water. This ‘dirty rocks’ approach was taken to provide tree roots with access to soil surrounding the trenches rather than to create an engineered root container, to maximise stormwater infiltration, and to maintain diffusion of gases between the atmosphere and the soil surrounding the trenches while supporting infrastructure loads. Seven soil trenches were used in the project, with a total volume of approximately 60 cubic metres (~130 tonnes) of crushed rock which was sourced from a local pit.

The rock had a neutral pH; other sources tested were rejected due to higher pH. The pavement base layer comprised 25-35 mm gap-graded gravel above the rock. Geofabric was used to separate the rock below from the pavement base rubble above. Geofabric was also used to line the sides of the trenches but not the base. 60 metres of 500 mm deep root barrier was used against the road edge compaction bench as required by the
Government of SA’s Department for Infrastructure and Transport’s engineers. Construction work was completed in autumn of 2018.

In total 9 Autumn Blaze hybrid maple (Acer x freemanii ‘Jefferesred’), 1 London plane (Platanus acerfolia) and 1 Dutch elm (Ulmus x hollandica) were installed in load-bearing tree trenches and 2 additional Autumn Blaze hybrid maples were planted in generous, de-compacted ‘block-outs’ to enable comparison of trees planted under usual practices with those in the tree trenches. Autumn Blaze hybrid maple was selected for most of the planting based on its community desirability, proven local performance and its deciduous characteristics providing summer shade and solar access during winter. The total cost of the project was approximately $40,000, the rock-filled trenches cost ~$34,000 (i.e. ~$570 per cubic meter installed) and tree supply and planting cost $6,000, with 11 of the trees planted into load-bearing tree trenches.

Autumn Blaze was planted in the engineered spaces on the northeast side of the road and trees of the same stock were planted at the same time into verge soil on the southwest side. The trees were watered until established using council’s water truck. After five years of growth the trees in the engineered spaces on the northeastern side of the road were visibly more advanced than trees on the southwest side (Figure 15).

Case study 3: Roadside tree trench, Dutton Road, Mt Barker, SA

Under normal circumstances a proposal to build a 3.5m wide shared-use pathway on a road verge would leave little space for tree planting. This was the case at Dutton Road in the centre of the Mt Barker township, where a path was needed to improve pedestrian and bicycle access and safety. Prior to its upgrade the verge of this collector road was available for informal parking including by heavy vehicles (Figure 16). Vehicle access and parking can compact soil to the extent that soil density becomes limiting to growth. Heavy equipment used during the road and footpath upgrading and undergrounding of powerlines would likely have further increased verge soil compaction. Additionally, soil on many road verges is often contaminated with (or replaced with) road materials which compact readily and can effectively prevent root penetration.
In 2009 Dutton Road was upgraded and the shared-use path was added. The 4.5 m wide verge allowed for less than 1 m for tree planting between the back of the kerb and edge of the path. To provide suitable soil for tree root growth a series of continuous trenches were excavated between the kerb and concrete path. The length of the trenches was limited by footings for light poles that were spaced nominally 25 m apart. The trench was excavated 0.6 m wide to 1.4 m deep, then backfilled with natural site soil after it had been loosened and blended with a highly refined compost material (Figure 17).

Chinese pistachio (*Pistacia chinensis*) trees were planted in winter 2010 and growth has been reliable and consistent since. The trees are now well established; they have canopies approximately 6 m tall and 5 – 6 m diameter. The trees have begun to shade the road in the mornings and the shared-use path in the afternoons (Figure 18). After 13 years of growth there were no signs of root impacts on the kerb or path assets which are now within ~250 mm of the trunks; the trunks were ~250 mm diameter at their stumps Figures 18 & 19).


Figure 18. Chinese pistachio established consistently in tree trenches excavated to 1.4m deep between the kerb and shared-use path (image: T Johnson 2023).

Figure 19. Chinese pistachios well-established in 0.6 m wide tree trenches showed no impact after 13 years on nearby kerb, road or path assets (image: T Johnson 2023).

**Case study 4: Planting roadside trees to calm traffic**

A high incidence of speed-related accidents focussed the attention of traffic engineers on a ‘black spot’ roundabout at the intersection of Bald Hills and Springs Roads. Speed of vehicles approaching the intersection from the southwest was implicated in some accidents. The speed limit on this section of road is 80 km/h. Traffic visibility on approach to the roundabout is affected by its location near the crest of a hill.

Local government traffic engineers are occasionally called upon to have trees removed on the basis of encroachment within motorists’ sight lines near intersections, yet some research counterintuitively shows more vegetation is safer. A study conducted in Melbourne showed that vehicle accidents involving pedestrians decreased as tree density and canopy cover increased (Zhu, Sze & Newnam, 2022). This may be due to trees increasing the visual complexity of roadsides, which increases driver alertness and attention and helps to reduce...
speed (Harvey et al. 2015). Trees also give a narrowing effect which is known to slow traffic (Kennedy et al. 2005), and peripheral vision of roadside objects such as trees contributes to speed perception (Lidestam, Eriksson & Eriksson 2019).

Based on this knowledge, to reinforce the perception of speed on approach to the Springs Road roundabout, trees were strategically planted on both sides of the road in 2015. A large species was selected, the Queensland kauri pine (*Agathis robusta*), which at maturity will visually restrict the space at the roadside and form a canopy above the road. To further benefit from the perception of speed, the distance between the trees was halved on approach to the roundabout to give the impression of increasing speed (Figure 20).

The first Queensland kauri pine on the right hand side is passed 190 m before the roundabout and the separation between the trees is 27 m; on approaching the roundabout the separation between trees reduces as follows: 27, 25, 23, 21, 19, 17, 15, 12 and 10 metres. On the left side a dense planting of eucalypts fills the verge at the start of the approach, but the spacing between the trees then mirrors those on the right side. At 80 km/h a car travels 22 m in one second and at 40 km/h this is reduced to 11 m/s, so unless a car has reduced speed to below 40 km/h on the approach the roundabout (Figure 21) the rate at which the trees are passed will give the driver the impression that speed is increasing. For a driver travelling in the opposite direction and accelerating slowly away from the roundabout the increased spacing between the trees might give the impression that speed is decreasing. It will be interesting to monitor the incidents at this roundabout and investigate their frequency as the trees mature.

**Case study 5: Urban forest species diversity and richness – species trials**

The Mount Barker District Council is committed to increasing tree canopy cover in urban areas and to ensuring urban forest resilience in the changing climate. Achieving these goals requires an increased palette of suitable tree species. To achieve this, Council plants small numbers of locally unfamiliar species to test their performance in Mount Barker’s soils and climate. Locations for planting trial species can include any public area such as a
roadside, traffic island, median or roundabout. Just as the previous case studies have shown that it is possible (indeed desirable) to integrate the design of infrastructure to protect valuable remnant trees, the design and construction of engineering assets can and should create space for significant trees of the future.

It has been shown that a 15m radius roundabout can accommodate a large River red gum (Case Study 1A), so this raises the question of what size roundabout might accommodate a tree as large and climate-resilient as a Moreton Bay fig? The answer depends more on the soil and available moisture than on the tree species; on alluvial soil near a creek or river the root zone may be much smaller, for example. With Mt Barker Creek only 40 m to the southwest, the 22 m diameter roundabout at the intersection of Dutton Road and MacFarlane Terrace might therefore easily accommodate a larger tree than the River red gum’s 30 m diameter roundabout on Red Gum Drive (Figure 22).

A smaller roundabout at the intersection of Flaxley and Alexandrina Roads provides insufficient soil volume for a large tree species but its high profile with many thousands of vehicles per day passing provides an opportunity to greatly enhance the aesthetics of the site by planting an unusual and attractive tree species selection. A locally unfamiliar tree species was selected but one which was considered highly likely to thrive: a Horse chestnut (Aesculus hippocastanum) (Figure 23).

*Figure 22. This Moreton Bay fig that is establishing well on a traffic roundabout will be a stunning green asset when it matures (image: T Johnson 2023)*
Discussion & conclusions

The projects summarised in this paper demonstrate that trees large and small can be protected on greenfield sites prior to, during and following development. By applying the same methods and standards new planting spaces can be created for saplings, to provide the root and canopy volumes and soil resources that will sustain them as they grow into large, iconic landmarks and beyond into their old age. These case studies demonstrate that tree protection and planting are readily achievable, but delivering the resulting urban forest requires the commitment of community leaders and decision makers.

Australian Standards now guide decision making and planning in relation to green infrastructure, with protection of existing green assets given highest priority amongst measures to increase canopy cover to reduce urban heat. Adequate soil volume, avoidance of soil compaction and contamination, and soil access to atmosphere for rain infiltration and gas exchange are essential. Protection of tree root zone integrity is paramount. Compliance with Australian Standards should be considered a minimum requirement. As urban heat is already responsible for more deaths than any other natural hazard and this is increasing, non-compliant, sub-standard urban tree protection and provision may soon be considered negligent.

Providing urban forest canopy equitably across communities needs multidisciplinary expertise. Collaboration across the disciplines of urban design, civil engineering, landscape architecture and arboriculture, from project scoping, planning, design and construction to commissioning and maintenance, is essential. Involvement of all disciplines at planning review stages is vital.

Trees are multi-functional, high-value community assets. They are essential urban infrastructure; they deliver essential and increasingly valuable services. They can be cost-effectively protected in greenfield developments, designed into street infrastructure renewal projects and upgrades, and retrofitted into existing streetscapes. Tree protection isn’t difficult, Australian Standards guide its achievement, it simply requires leadership and commitment. The designs and approaches presented in this paper are realistic, are in current use, and should be considered for further use in appropriate locations.
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Abstract
Urbanisation has delivered society many benefits but has also created problems. Low albedo and high thermal mass create urban heat islands. Altered hydrological cycles can lead to downstream flooding or desertification, pollution, and erosion. Loss of vegetation and the resulting nature deficit increases human physical and mental health disorders and diseases. With traditional engineering and urban design approaches problems have increased as city size has increased. More of the same can’t fix this. The solutions to these issues will be holistic, multidisciplinary, and focused on life. Traditional urban engineering is evolving to support urban green life that manages stormwater, moderates microclimates, remediates soils and sustains the micro and macro biodiversity we can’t live without. This paper reports research and case studies that show green engineering can support life and engineering outcomes simultaneously. Research and working demonstrations are detailed that show infiltration devices and porous surfaces can provide effective stormwater management solutions in roads, on verges, in car parks, on parks and reserves and in private gardens. Green engineering solutions support urban forests and the vegetation enhances the efficiency and effectiveness of the engineering, which combined help to restore nature’s circular systems in urban areas.

Introduction
Urbanisation’s increasing demands on infrastructure provision and impacts on environmental sustainability have been serious concerns for decades. Highly developed impervious urban catchments raise stormwater discharge volumes and reduce soil water recharge, create urban heat islands and decrease water availability to urban vegetation. Diminished creek and river base flows and poorer water quality in creeks and rivers lead to local extinctions of aquatic and terrestrial species, degraded marine environments, and reduced human health and wellbeing.

Green engineering approaches based on or incorporating water-sensitive urban design (WSUD) can help to address these problems. WSUD is a major component of green engineering, it’s aim is to detain and manage rain where it falls. WSUD can improve the efficiency of stormwater management by reducing costs associated with traditional pipe networks, instead using the water to deliver human and environmental benefits locally. Emerging from the last decade of the last millennium, the adoption of WSUD was helped by policy introduced nearly 20 years ago (National Water Commission, 2004) which set capacity-building targets toward creating water sensitive Australian cities.

Following at state level, in South Australia the functions of the Stormwater Management Authority (SMA) were updated in the Local Government Act 1999. The SMA’s updated goals guided progress to more effective use of urban stormwater for environmental and sustainability outcomes: ‘...for the maintenance of biodiversity, ...for human consumption and ...other appropriate purposes.’ Another function of the SMA is to facilitate programs by councils to address such matters.

Putting new policy into practice usually requires innovative approaches for which standards do not yet exist. The absence of WSUD and green engineering standards in the standards-driven arenas of local government and civil engineering constrained it to trials and research projects; it is still not widespread and mainstream after two decades of policy direction but its use is increasing. Resistance to a new approach or change in practise is common, and this was the case when policy proposed the merger of green and grey infrastructure goals.

Trees have long been viewed as problematic or even destructive to utilities, pavements and other built assets above and below ground, and efforts to increase tree canopy cover continue to meet resistance as a result. However, trees have been combined with WSUD devices and other engineering approaches with good effect. Devices and systems like rain gardens, green roofs and walls, infiltration trenches, leaky wells, pervious pavements, bioretention systems, swales and buffer strips, sedimentation basins and constructed wetlands can
all be designed to incorporate trees and other vegetation. These systems can infiltrate stormwater more efficiently than parkland surfaces such as grassed areas, and so can help to restore pre-development runoff regimes with minimal land requirement. Through appropriate design any problematic interaction between natural and built assets can be greatly reduced, and research has begun to identify and quantify benefits of combining trees with WSUD devices.

Trees can help to manage stormwater quality and quantity; they intercept rainfall, increase infiltration, and convey much of what is detained in the soil back to the atmosphere (Thom et al. 2022; Grey et al. 2018; Szota et al. 2019). Pollutants that can be toxic to aquatic and marine life can be harvested to nourish trees and aid their growth (Denman et al. 2016). Soaking harvested stormwater into tree root zones can increase tree hydration and increase photosynthesis, transpiration and growth of saplings and mature trees (Gleeson et al. 2022), and it can reduce ground movement effects of trees in reactive soils (Johnson et al. 2020). Opportunities exist to deliver these benefits by combining trees with appropriate, compatible engineering.

Integrating trees and other vegetation into urban engineering is becoming easier as knowledge and expertise increase at the boundaries between the engineering, horticulture, arboriculture and landscape architecture disciplines. Interdisciplinary knowledge and collaboration have increased markedly in the two decades since the National Water Initiative and industry and Australian Standards now exist to inform planning and design for construction and protection of urban green infrastructure (UGI). The new Handbook, Urban Green Infrastructure – Planning and decision framework (Standards Australia, 2023) provides guidance for planning and decision making and is relevant to works on public and private land. Application of the approach described in this new handbook and compliance with AS4970-2009 Protection of trees on development sites and AS2303-Tree stock for landscape use should be considered as the mandatory minimum standards required for protecting existing trees and providing new saplings. To guide WSUD planning, best practice manuals exist in some jurisdictions and preparation of standard drawings is well progressed in South Australia. Applying Arboriculture Australia’s MISS06 Tree Valuation, the industry’s accepted minimum industry standard on tree valuation, to reliably attribute financial values to tree assets (Wilson, 2022), is also appropriate to inform project scoping and planning decisions.

With increasing knowledge, tools and standards, tree protection and provision are becoming more mainstream, standardised and effective. Research is ongoing and mainstreaming will help to deliver improved designs, efficiency and effectiveness, but much is now known from many early projects. Projects built over the past decades that continue to provide problem-free service with little or no additional maintenance requirement indicate that more widespread application is warranted. This paper summarises the authors’ experience with some UGI devices and approaches over nearly two decades. The use of soakage trenches, kerb inlets and leaky wells, and pervious pavements is described, including some updates on projects that have been introduced at Treenet symposia previously.

Soakage Trenches

Soakage trenches detain water and allow it to infiltrate the soil where it can be accessed by trees and other vegetation. Soakage systems were common in South Australia for much of the early and mid-20th century, for disposal of stormwater and effluent, but more recently ‘waste water’ is conveyed through pipe networks to treatment works or to receiving waters. Stormwater soakage system trials built in the City of Mitcham over the last two decades were combined with vegetation as trees are known to increase infiltration rates in fine soils (Day and Dickinson, 2008), thereby increasing the capacity and efficiency of the systems. Road runoff now irrigates many reserves and sustains healthy trees and vegetation in the City of Mitcham.

Stormwater from surrounding streets has recharged subsoil moisture at Burbank Reserve at Bedford Park since 2009. All runoff from three tennis courts (1,500 m²) in Naomi Terrace, Pasadena has soaked into the adjacent reserve since 2014, likely almost doubling the soil moisture that was previously available to the reserve’s trees. In 2015 a series of leaky wells was built to soak stormwater harvested from Freeling Crescent into the root zones of heritage-listed River red gum trees adjacent to Colonel Light Gardens Primary School. In 2017 over 180 linear metres of soakage trench was built in reactive soil at Thurles Reserve, St Marys, which harvested stormwater from three of the four adjacent roads to support a diverse planting of ornamental, fruit and nut trees. These
systems and others were based on the innovative work of The Late Prof. John Argue, in particular his working example built in 1991 that continues to harvest runoff from 18 townhouses to provide passive irrigation to Rowley Reserve, Brompton (Argue 1999, 2004; Water Sensitive SA 2020). Details of soakage systems in Dorset Avenue, in Netherby Reserve and in Skitch Reserve that were based on Prof. Argue’s work are provided below.

**Where to use soakage trenches:** the ongoing, trouble-free operation of the stormwater soakage trenches reported in this paper demonstrate their suitability for use on large and small public reserves including in reactive soil of low hydraulic conductivity. Combining soakage trenches with tree cover will improve their efficiency and effectiveness.

**Benefits of soakage trenches:** strategically located soakage trenches across urban catchments will reduce stormwater nutrient loads and discharge volumes, improving downstream aquatic and marine environments and potentially generating substantial savings by avoiding the need for pit and pipe infrastructure upgrades. Increased soil water recharge in semi-arid and arid regions will enhance tree transpiration and growth, increase shading, and mitigate urban heat island effects. Soakage trenches will support biodiversity conservation and urban forest resilience in the changing climate by increasing the range of species that may be planted.

**Dorset Avenue**

A soakage system built in a verge in Dorset Avenue, Colonel Light Gardens in 2008 (Johnson, 2009), as an addition to a kerb, gutter and road renewal project, continues to demonstrate the effectiveness of this approach after 15 years of trouble-free service. Water harvested from the road by a 0.6 x 0.9 m side entry pit flows into the trench through a coiled agricultural drainage pipe which serves as a filter (Figure 1). The base of the pit was not sealed; the soil at its base and part of the agricultural pipe were covered with a layer of 20 mm gravel. The 9 m long, 0.9 m wide soakage trench was filled between 0.75 m and 1.5 m deep with 60 mm stone. Stone was wrapped in geotextile then covered with soil excavated during trench construction. Note that the site’s topsoil with its high organic content should be reinstated at the surface following construction.

![Figure 1. Adapted side entry pit design used to harvest, filter and convey stormwater received from a road to a soakage trench.](image)

Built in desiccated moderately reactive clay soil near the end of the 1997 – 2009 Millennium Drought the potential for reactive ground movement at this site upon re-wetting was considered to be substantial. The catchment area includes road and footpath surfaces along 90 m of road, the roof of a local hall, and part of the rooves of two homes. Adelaide receives 80% of its 560 mm average annual rainfall at intensities not exceeding 4 mm/hr, so flows bypassing the pit are uncommon. In a year of average rainfall it is likely that this system harvests over 100,000 litres of stormwater.

15 years after construction the kerb and gutter along the street has developed minor hairline cracks in some places but generally it remains in very good condition. No cracks in infrastructure have been observed near the soakage trench but they have been observed elsewhere in the street. No issues or problems have been observed in the road surface in the vicinity of the pit and trench since this infrastructure was built. Apart from the presence...
of the drainage pit, the only other obvious difference between the area near the soakage trench and elsewhere in the street more distant from it is that beneath the trees near the soakage trench the shade appears much denser than elsewhere (Figure 2).

![Figure 2. Shade density beneath the mature tree nearest the soakage trench (right hand side of the road, pit is visible near centre of image) was greater than beneath other trees along the street.](image)

Litter and clogging-related maintenance requirements were investigated at the Dorset Avenue soakage trench. Litter was not managed in the pit for the first 9 years; the usual practise of annual vacuuming was not conducted at all in the first 9 years of operation yet the system continued to function. The deciduous native White cedar (Melia azedarach) trees that line the street shed flowers, fruits, leaves and twigs so litter built up in the pit and at times it covered the filter, but the litter was not removed. After nine years without maintenance stormwater inflow was consistent at ~70 litres/minute. Litter that collected in the pit soon decomposed, i.e. in-situ composting, which may have been enabled or enhanced by biological activity through the unsealed base of the pit.

**Netherby and Skitch Reserves**

In March 2016 a soakage trench system was built in Netherby Reserve to manage localised flooding in Bartley Avenue, Netherby. Surface flows along the road and verges had caused localised flooding at times, so a system was designed to divert surface runoff into a drainage pit on the road frontage of Netherby Reserve, from which soakage trenches extended into the reserve. The capacity of the system and the infiltration into the reserve soils reduced surface flows and alleviated the frequency and extent of localised flooding. Construction of the reserve soakage system and associated drainage beneath the road was calculated to have saved $150,000 (AU$ in 2016) compared with extending deep drainage between the reserve and the nearest pipe network downstream. A summary of this project provided at a Treenet symposium workshop is available as a video (Johnson & King, 2019).

Trees planted in Netherby Reserve following the Millennium Drought but prior to construction of the soakage system had failed to thrive due to insufficient subsoil moisture. Although the reserve’s irrigation had been recommisioned following the end of water restrictions when the drought broke, turf irrigation is typically shallow, rarely supports tree growth, and can result in shallow tree root development. However, the growth rates of trees planted following construction of the soakage system exceeded expectations. English oak (Quercus robur) is commonly understood to grow slowly, but with subsurface irrigation supplied by the stormwater soakage trenches this species achieved apical growth exceeding 1.4 m per year in the first few years (Figure 3).

Trouble-free function of the early soakage trenches led to their wider use, including in small pocket parks, to enhance amenity, biodiversity conservation, cooling, and to manage stormwater. In 2019 a soakage system was built in Skitch Reserve, Melrose Park; a housing allotment-scale pocket park. The concept was simple: a side entry pit was built immediately upstream from an existing drainage pit that connected into the pipe network.
The new pit diverted storm flows into the reserve soakage system until full, after which the gutter flow then bypassed the soakage system pit and continued down the gutter and into the downstream pipe network (Figure 4).

Figure 3. English oak saplings planted after the soakage system was installed have thrived.

The soakage trenches used in Netherby and Skitch Reserves were smaller than the original trial in Dorset Avenue; at 0.45 m wide they were half the width and they were less than 1 m deep (Figure 5). The shallower, narrower trenches were built with a level base and the slotted pipes were installed level to promote even water distribution and infiltration along their length. The smaller soakage trenches were quicker and cheaper to build and are probably more efficient, given that their greater surface area to volume ratio is likely to enhance infiltration. Trenches were fitted with a vented riser positioned beneath a vented valve box (i.e. 2 x 25 mm diameter holes were drilled in the lids) at the end of each pipe run to allow air to escape and so speed stormwater ingress.
Figure 4. Plan view of Skitch Reserve soakage system to intercept and infiltrate stormwater from Winston Avenue.

Figure 5. Cross-sections (top) and longitudinal section (bottom) showing the small, level design used to distribute water evenly throughout Skitch and Netherby Reserves.

The 24th National Street Tree Symposium 2023
Kerb Inlets

Early stormwater harvesting trials conducted adjacent to the Waite Arboretum in Claremont Avenue were reported at Treenet's 2003 symposium (Porch, Zanker & Pezzaniti, 2003). Operational issues with early infrastructure were examined during Treenet's symposium field day five years later (Lawry, 2008). These early investigations sparked ongoing research that led to the development of the kerb inlet and 'leaky well' (Figure 6) as was used in initial research projects. A beauty of the kerb inlet design is that it can be connected to soakage devices of any size and shape for any street verge or other application. A working kerb inlet in a street in the City of Unley was demonstrated at the 2010 Treenet symposium's field day (Lawry & Smith, 2010).

An experiment to evaluate the performance of the kerb inlet began when road and drainage asset renewal in the City of Mitcham provided an opportunity to install 28 inlets in Eynesbury Avenue, Kingswood, in 2014. Infiltration performance and water quality benefits of the inlets were investigated, and the research installation also served as a working demonstration. The backfill media in the Eynesbury Avenue experiment included washed gravel (14 mm Stonyfell quartz screenings) but it also tested the site's silty clay loam, a commercially sourced sandy loam, and a self-granulating, clay-based waste product of water filtration ('SPACE', Space Down Under, Adelaide, South Australia) (Sapdhare et al., 2018; Sapdhare et al., 2019). Gravel supported the highest infiltration rate in the local soil, followed closely by the SPACE which had the added benefit of a very high cation exchange capacity which gives it greater potential to contribute to pollution management including heavy metals.

Concerns are routinely raised regarding the potential for problems to arise from infiltration into reactive soil but very little research has been conducted to inform this. Shrinkage of reactive soil upon drying is well understood, and the contribution of trees to this effect through water extraction is known, so logic suggests that offsetting the water loss due to trees through infiltration might reduce ground movement (Goldfinch 1995). To help to inform this with regard to infiltration through kerb inlets, kerb elevations were surveyed along Eynesbury Avenue to measure ground movement. Survey points were established at the locations of the inlets and wells, and midway between them. The experiment revealed that there was no difference between ground movement at the infiltration points with inlets and at points without infiltration midway between the inlets. Infiltration

![Figure 6. Kerb inlets divert stormwater into soakage wells located in Eynesbury Avenue's verge.](image-url)
through inlets into moderately reactive soil did not induce ground movement during the study period from 2014 to 2016.

To investigate the benefit of these dispersed, small-scale stormwater harvesting devices at the catchment scale a larger study was established in suburban Hawthorn (34°58'30.7"S 138°36'10.0"E). This study measured the cumulative benefit of 183 inlets (model R-750, Space Down Under, Adelaide, Australia). Catchment outflow and rainfall data were collected for 12 months before the inlets were installed across the 17.5 hectare catchment; these data were used to calibrate a model to predict outflows under the catchment’s conditions prior to installation of the inlets (Shahzad et al., 2021). Comparison of the modelled flows with data measured following installation of the inlets revealed the effect of the inlets on discharge volume and concentration time.

The study showed that under field conditions in an established residential area (i.e. with minimal sediment but abundant tree litter build-up between routine road sweeping) the average harvest volume per inlet was 1.6 kilolitres in 2017 and over 2018 the average harvest was 1.4 kilolitres per inlet (Shahzad et al. 2022). The difference in harvest quantity over these two years was due to rainfall variability. Distributed kerbside stormwater storage and infiltration devices were shown to be effective in managing flows from small to medium storms, and modelling showed that with increased storage volume inlets and wells ‘...could provide a significant reduction in the runoff volume and flow rate at the catchment scale (Shahzad et al. 2022). The inlets continue to provide maintenance-free service after nine years in-situ.

In an ongoing study in the Hawthorn sub-catchment the benefits of the harvested stormwater to street tree growth and urban cooling are under investigation. Research by Flinders University staff and students has shown that mature White cedar (Melia azedarach) trees with inlets in their root zones transpired 29% more water during summer than similar trees without inlets (Gleeson 2022). Additionally, photosynthesis was 94% higher, trunk diameter increased 25% more and height increased 50% more for White cedar saplings with inlets than for saplings without inlets.

**Where to use kerb inlets:** anywhere where there is a kerb and gutter near vegetation. Inlets will benefit trees and communities particularly in urban streets with impermeable surfaces and high levels of urban heat, even in narrow streets with narrow verges.

**Benefits:** Increased transpiration in mature trees and faster growth of saplings have been demonstrated. Stormwater quality and quantity benefits result from widespread distribution of inlets across urban catchments.

**Permeable paving**

Permeable paving delivers trafficable surfaces, stormwater quality and quantity benefits, enhanced ecosystem services, and reduced tree root impacts but its use is still the exception in Australia despite decades of application internationally. Updated pavement base design software (DesignPave v2.0) is available for free download to aid structural and hydrologic design of permeable pavements (CMAA, undated), including on low strength subgrades that can support tree root growth. The authors’ experience with permeable paving began when solutions were needed to manage stormwater and prevent pavement damage associated with tree root growth.

Pavement surfaces are damaged when forces exerted by radially expanding tree roots exceed the shear strength of subgrades, pavement base materials, or the wearing surface. A layer of gravel has been demonstrated to deter tree root growth (Cline et al., 1980; Hakonson, 1986; Reynolds, 1990, Gilman 2006), and gravel used for structural and stormwater detention purposes beneath permeable paving has shown a similar root-deterrent benefit in experiments conducted in Adelaide (Johnson et al. 2019) and on the Sunshine Coast (Lucke and Beecham 2019). The highly porous gravel base protects the pavement assets and the trees; it provides stormwater detention volume to increase infiltration to nurture trees, and it supports seasonal drying of the gravel base and the subgrade surface which suppresses shallow root growth.

Examination of Callery pear (Pyrus calleryana Chanticleer) roots after 5 years of growth in the Adelaide experiment (Johnson et al. 2019), and of Broad-leaved paperbark (Melaleuca quinquenervia) roots 4.5 years after planting on the Sunshine Coast (Lucke and Beecham 2019), revealed significant differences in root development beneath permeable and impermeable pavements. Beneath permeable paving there were more...
fine, non-woody roots but fewer coarse, woody roots in the subgrade than beneath impermeable paving. Beneath permeable paving the larger diameter roots were also deeper in the subgrade than was the case beneath impermeable paving. Fine roots in the gravel layer beneath the permeable paving were of a seasonal nature and did not exceed 2 mm in diameter; evidence of seasonal fine root turnover was abundant. The study concluded that the gravel layer did function as a root deterrent; the gravel served as a buffer between the pavement surface and thickening roots in the subgrade. Growth of thicker, woody roots deeper in the subgrade beneath permeable paving further reduces the likelihood of pavement damage.

Updating the previously published results, after ten years of tree growth the Adelaide experiment’s footpath pavement sections were lifted to examine the Callery pear trees’ structural roots. The trees at this time had attained trunk diameters of over 200 mm in the 600 mm wide tree pits. Structural roots had not grown into permeable pavement gravel base layers immediately adjacent to the planting pit (Figure 7).

With the geotextile lifted and the soil washed away it was clear that all of the structural roots had developed outside the gravel and grown vertically downward to at least the depth of the pavement’s subgrade. Some roots had grown horizontally beneath the gravel without having entered the base layer (Figure 8). This growth habit was observed consistently at all of the six permeable pavement sections that were excavated for root examination. Pavement repair and root removal were required at impermeable concrete block paved sites after 10 years of street tree growth, but repairs were not required at sites with permeable paving.

Figure 7. Structural roots did not develop in the permeable pavement gravel base layer.

Figure 8. Structural roots descended outside the gravel base before developing horizontally in the subgrade. The string marked the edge of the header course 600 mm behind the kerb. Scale shows centimeters and inches.
The gravel base layer beneath permeable paving consistently prevented the shallow growth of large roots which is often observed to damage paving and create tripping hazards. Not compacting the subgrade, as suggested by Eisenberg et al. (2015), Drake et al. (2013) and others for hydrologic benefit, is likely to support this root growth habit. Uncompacted low-strength subgrade allows root penetration, elongation and radial expansion at depth. Compacted subgrade restricts root penetration and growth and, because compaction increases subgrade strength, if a root did develop along a line of weakness in or beneath compacted subgrade then it might impact the subgrade as a structural unit and thereby cause greater damage.

In a garden adjoining one of the permeable pavement sections in the Adelaide experiment a Hill’s weeping fig (*Ficus microcarpa* var. *hillii*) had been planted in 2009. Separate roots from this tree grew beneath imperious paving (Figure 9) and beneath permeable paving (Figure 10). Beneath imperious paving the *Ficus* root growth habit was similar to the shallow growth of Chanticleer callery pear beneath imperious paving: it required roots to be cut and removed to enable footpath repair. A larger root from the same tree grew beneath a pervious pavement section 3.5 m to the north of the root shown in Figure 9. Beneath the permeable paving this larger root grew at the interface of the gravel and subgrade (Figure 10).

![Figure 9. Shallow Ficus root growth beneath impervious concrete block paving](image)

![Figure 10. Deep Ficus root growth beneath pervious paving with a gravel base layer (the tree from which this root grew is visible in the top right of the picture).](image)
Following extensive research and ongoing development the City of Mitcham revised its standard design for permeable paved footpaths with the view to reducing asset life cycle costs and achieving environmental benefits. Damage to footpath assets will be avoided or reduced and injury to trees will be eliminated or reduced through the use of permeable paving, which will reduce expenditure on pavement repairs and tree replacement while enhancing ecosystem services and benefits to residents. The cost of permeable paving remains slightly higher than impermeable paving due to supply and demand, so the City of Mitcham has sought ways to reduce construction costs. As in all areas of council business the search for cost effectiveness and efficiency in asset management is ongoing, and WSUD and other innovations should continue to become more cost effective as new materials and processes are mainstreamed.

Mitcham’s revised footpath pavement base design uses a single layer of 10 mm gravel in its base, above uncompacted subgrade (Figure 11). The 10mm gravel base replaced the previous two-layer base with its 5-7 mm gravel bedding layer above 14 – 16 mm gravel. The standard design for permeable paved footpaths uses a sand bedding layer above a base layer of compacted quarry rubble. The new permeable design with its single material and single operation for base construction will generate savings compared with cartage, storage and handling of two bulky quarry products and construction of two separate base layers. This should more than offset the currently marginally higher cost of permeable paving to make permeable paving less costly to construct than impermeable paving. Elimination of subgrade compaction reduces time and construction equipment requirements to generate further saving. Such savings are unlikely to be delivered in the short term however, until enough contractors become familiar with the work to be confident enough to begin to compete on pricing.

Figure 11. The City of Mitcham’s adopted design for some permeable paved footpaths utilizes a single 10mm gravel base layer on uncompacted subgrade.

The City of Mitcham’s experience with permeable paving in footpath situations led to trials of its suitability for use in road surfaces. A trial in Kegworth Road, Melrose Park was designed to resolve regular local flooding issues (Figure 12). The use of permeable paving also supported the good health of significant large trees in the reserve adjacent and additional plantings in the streetscape. To maximize exfiltration the subgrade was not compacted; in its saturated state it had a Californian Bearing Ratio of 3%. Drainage was installed in the gravel base (Megaflo 170, Geofabrics Australasia) but was perched in the gravel above the subgrade to support infiltration prior to excess water during storm events being drained to leaky wells in road verges and soakage trenches on a nearby reserve. 80 mm thick Ecotrihex pavers were used above a 50mm thick bedding layer of 5-7 mm screenings and 175 mm thick base layer of 20 mm screenings. 2-3 mm sand was used to fill the joints and voids between the pavers.
Figure 12. Permeable paving resolved a localized flooding issue at Kegworth Road, Melrose Park, saving $1M compared with the cost of upgrading existing pit and pipe drainage.

The area of permeable paving at Kegworth Road was less than 600 m² and it received stormwater runoff from a large suburban catchment. Dispersing WSUD infiltration devices throughout catchments would be a better way of preventing the localized flooding downstream, i.e. to prevent the downstream problem rather than to treat its symptoms, so this example may present a ‘worst case’ scenario in terms of repeated saturation. The Kegworth Road solution has proved successful, however some settling of the surface occurred over a trench alignment in its first few years. Settling of utilities trenches is a common problem in streetscapes with sealed roads too, and the ‘worst case’ aspect of drainage from an expansive catchment may have contributed to it happening more rapidly in this instance.

Early Australian experience with permeable paving includes Olympic Park and Smith Street, Manly, in New South Wales, Kirkaldy Avenue, Henly Beach in South Australia and other examples that date from the 1990s. These examples remain fully functional. Some other SA examples include Holland Street in Thebarton (City of West Torrens), Alfred Street in Walkerville (Town of Walkerville), Enterprise Lane in Hyde Park (City of Unley), and Druid Avenue in Stirling (Adelaide Hills Council).

**Where to use permeable paving:** Urban footpaths with adjacent street trees (particularly prior to planting), plazas, patios, residential roads, carparks.

**Benefits:** Avoid or delay root-related pavement damage, hazard, risk, expense and liability; reduced injury or loss of trees during maintenance.

**Porous asphalt**

Open-graded or porous asphalt has been widely used as a wearing course over impervious asphalt for many years; it reduces traffic noise, reduces or prevents plumes of water spray that can obscure visibility and it can help to reduce aquaplaning. In these applications the surface water flows into and through the voids in the asphalt to the road edge where it can drain away into conventional drainage systems. Major roads carrying vehicles traveling at higher speeds benefit most from the noise attenuation, splash, spray and aquaplaning reduction (Isenring, Koster & Scazziga, 1990). There are also substantial pollution reduction benefits, most likely due to the double effect of reduced splash removing less material from the undersides of vehicles and the trapping of contaminants within the pavement surface (Barrett, Kearfott & Malina 2006). Porous asphalt systems have also been developed using waste tyre rubber content to add flexibility, maximise fatigue resistance, and to reduce reliance on virgin materials and synthetic binders.

Recent innovations in techniques developed to create a structural underlying pavement base for permeable block paving that is suitable for roads have been applied beneath porous asphalt to capture and infiltrate the water to the underlying soils and street tree roots. The underlying base is constructed using the same method as permeable paving with an embedded geogrid system to distribute the load, however with a 75-100mm thick
layer of porous asphalt over the top of the screenings made with recycled waste tyre aggregate that provides a resilient surface layer. The City of Mitcham collaborated with researchers based at the University of Melbourne to conduct an experiment in a full-scale working carpark in St Marys in South Australia. The experiment tested the porous asphalt and pavement structure under field conditions and demonstrated that these systems are viable for sustaining low to medium traffic loads (Raeesi et al., 2021).

Porous asphalt has a higher infiltration rate to most permeable pavers (Raeesi et al., 2022), and, while it is expected to reduce over time due to clogging, relative to clogging in permeable paving and even without regular maintenance the asphalt’s infiltration rate remains well above local South Australian rainfall intensities. Water that soaks into porous asphalt base layers then infiltrates into the underlying soils where it can provide moisture to trees and reduce pollution impacts on local environments (Raeesi et al., 2022). Following the successful trial at St Marys, porous asphalt has been used in many applications by the City of Unley to support the health of newly planted trees and as part of streetscape upgrades to sustain mature trees.

Unlike permeable paving, porous asphalt visually blends with conventional asphalt road surfaces which reduces the potential for distraction and unnecessary delay of motorists. Porous asphalt may also more readily fit the required dimensions and site constraints of the Manual of Uniform Traffic Control Devices (Standards Australia, 2021) than block paving. As an example, porous asphalt was used around significant trees in Dunrobin Street, Black Forest (Figure 13) where the kerb alignment could not be altered and where the previous kerb had been overgrown by the trunks of trees. The porous asphalt sections now work in harmony with the trees; they ‘future proof’ the site against further kerb lift. While the effects on trees due to the porous asphalt have not yet been investigated, the gravel layer and seasonal drying of the subgrade surface beneath the porous surface are likely to retard shallow root growth similarly to the block paving effect described previously and the infiltration of water is likely to deliver similar benefit to that shown in response to infiltration through inlets in the experiment in Hawthorn.

![Figure 13. Porous asphalt construction in Dunrobin Street, Black Forest, used kerbing to create a build-out which was temporarily filled with screenings prior to installing porous asphalt.](image)

**Where to use porous asphalt:** Carparks and local roads are ideal to convert to infiltration zones, with or without existing trees, as are streetscapes and parking spaces where new trees are to be planted.

**Benefits:** Reduced water ponding, increased shade and transpiration, larger and denser tree canopies, reduced heat island effects, reduced downstream stormwater quantity and quality issues, reduced risk of trip hazards and related liability and expense.

**Discussion**

The benefits of soakage systems, kerb inlets, swales and other stormwater harvesting devices have been reported in relation to Australian research and trials over many years. System performance has been quantified in working demonstrations in urban streets including in areas with moderately reactive clay soil. Enhanced tree growth and transpiration have been reported (Gleeson et al. 2022), as have stormwater quality and quantity
benefits (Sapdhare et al, 2018, Sapdhare et al. 2019; Shahzad et al. 2021, Shahzad et al. 2022). Devices that have operated over years and decades with little or no maintenance remain fully functional. These well-established Australian examples show that urban green infrastructure and water sensitive urban design work from environmental, engineering and human perspectives.

The soakage trench system at the City of Charles Sturt’s Rowley Reserve in Brompton has been in operation since the surrounding townhouse development was completed over thirty years ago. This site was previously a ‘pughole’ (a quarry where clay was sourced for the local brickmaking industry) before it was partly filled to create the Rowley Park Speedway and subsequently filled more to provide a level site for housing. The continuing operation of Rowley Reserve’s soakage system on this reclaimed fill site after thirty-two years of trouble-free service, with the surrounding townhouses remaining in apparently excellent structural condition and the reserve a cool, green, real estate value-adding oasis, is proof that these high-functioning systems can have long service lives, be cost effective, and present minimal risk.

The installation of some of the City of Mitcham’s devices into desiccated soil during the Millennium Drought preceded massive fluctuation in rainfall. In subsequent years the lowest annual rainfall total of 338 mm (2015) and the highest 820 mm (2016) - the second highest ever recorded – were 38% lower than and 51% higher than Adelaide’s annual mean of 541 mm. In 1992, one year after the Rowley Reserve system was built and when the trees were still saplings, it received and managed 63% more than Adelaide’s average annual rainfall, i.e. 883 mm total annual rainfall. Through these rainfall extremes no problematic shrink-swell effect or built infrastructure impact has been observed in relation to kerb inlets or larger soakage devices like the trenches referred to in this paper.

Although many in the industry still raise concerns that stormwater infiltration into reactive soil may be problematic, published research and local examples working over long periods indicate to the contrary. Research shows that infiltration near trees can marginally offset some of the settlement that is due to trees, which seems logical. Much infrastructure damage occurs due to settlement during drought conditions; it seems logical that infiltration may also offset this seasonal effect to some degree. In contrast, urban drainage and impervious surfaces that prevent soil moisture recharge might contribute to increased settlement during dry periods and so present the greater risk.

Cost is still cited by some as a barrier to adoption of UGI and WSUD. This is surprising because accurate life-cycle costs are unavailable. The actual life-cycle costs of these innovative approaches will become clearer as initial installations approach their service life spans. Costs of materials are typically higher early in a product’s life cycle, with innovators and early adopters paying a premium but prices then becoming more reasonable as demand increases. Contractors unfamiliar with new approaches may charge a premium before mainstreaming increases competition in the market, but novel practices can still save money. The integrated design approach in the Kegworth Road permeable paving job, for example, saved $1 Million compared with business-as-usual pit and pipe extension.

The City of Mitcham’s permeable paved footpath standard with its single base layer design using a single material is likely to be cheaper to construct than the previous double layer bases for permeable and for impermeable paving. Lower life cycle costs have been reported in a UK comparison between permeable and impermeable pavement options (Wilson, 2006). Not only did permeable paving options cost less than impermeable paving in the UK comparison where WSUD has been mainstream for decades, the permeable option avoided substantial additional costs associated with conventional drainage requirements of impermeable pavement.

Risk is sometimes cited as a reason to be cautious of new and ‘unproven’ approaches. Just as life-cycle costs are unknowns with any new innovation, so UGI risk must also be considered unknown. This presents a real dilemma for asset managers who must choose between the unknown that might possibly involve a greater degree of risk than an accepted business as usual approach, but the risk of the unknown might also be less than the known and universally accepted risks of BAU. An alternative perspective might be to accept the realities that current approaches are delivering increasing problems (e.g. UHI, flooding, pollution, erosion, increasing built asset costs) and that more of the same will inevitably increase these problems further, so risk from BAU should not be accepted but considered as an increasingly expensive and problematic certainty. The risk manager’s decision
might then be more clearly framed as a choice between an innovative solution that may eventually require some remedial action or an increasingly expensive and unacceptably problematic certainty.

There will always be unknowns with every new process or technology; these diminish with ongoing research. Unknowns regarding the consequences of long-term application of long-held standards and business as usual practices similarly diminish with time and research. Research over past decades has shown that fears surrounding UGI impacts are unfounded and that UGI benefits are generally greater than initially anticipated. Conversely, well-established grey engineering approaches have been shown to contribute to unsustainable and increasingly problematic environmental issues that are expensive to mitigate.

New capital works and asset renewal projects are funded routinely in council budgets and these provide opportunities to tap into the substantial long-term savings and benefits of WSUD and UGI options. Designing green assets into towns and cities, protecting and nurturing existing mature trees, and creating spaces for new trees aren’t difficult tasks provided green engineering thinking begins at the project scoping stage and continues throughout the project. Appropriatelyscoping UGI outcomes at project commencement will help to ensure the required interdisciplinary expertise will be brought to all project stages. It’s not a difficult task nor should it be considered risky, as since March 2023 it is informed and guided by Australian Standards’ Urban Green Infrastructure – Planning and decision framework. Choosing to not comply with the Australian Standard (as a minimum) must surely present greater professional risk.

Conclusion

South Australian experience with passive irrigation of urban trees through stormwater harvesting and infiltration exceeds thirty years. Treenet’s experience with stormwater harvesting and infiltration into road verges through kerb inlets extends over twenty years with units installed on residential, collector and arterial roads. Local experience with permeable paving began with the earliest installations dating from the 1990s. All of these systems have shown benefit to residents, local and downstream environments. None of these approaches have resulted in problematic outcomes as were predicted by many, either in years of high rainfall or low, yet unfounded concern continues to dissuade many asset managers from adopting urban green infrastructure and water sensitive urban design approaches.

The case studies reported in this paper show that the paradigm is shifting. The change to urban green infrastructure is accelerating. A goal of this paper is to encourage the further uptake and more widespread trial, application and research of urban green infrastructure. It is hoped that this paper will encourage asset managers to be open to opportunities provided by annual capital works programs to test such devices as kerb inlets and soakage wells, soakage trenches, permeable block paving and porous asphalt. Engaging in discussion with research institutions during project planning will inevitably identify opportunities to collaborate and to increase knowledge and understanding based on the performance of working infrastructure. The alternative is to perpetuate the increasingly expensive, problematic and unsustainable status quo.

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**The 24th National Street Tree Symposium 2023**

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88


The 24th National Street Tree Symposium 2023


THE ART OF TREE PHOTOGRAPHY

Graham Gall
Graham Gall Photography

‘Photographers speak of capturing the moment. What’s even more exhilarating is to be wakeful enough to see the moment before it occurs.’ Steve Parrish

Abstract
I approach tree photography as an artist but when commissioned I must also meet the needs of the client. A commission for any work of art requires a relationship to be built between the artist and the client. It is important to have open communication and discuss what the client’s expectations are and then to educate them on your creative vision and approach to the project as well as any technical issues that may impact on your work. Depending on what the client asks for and how much work you are taking on, commissioning any work of art is a long process that should not be rushed. What if you are shooting an image yourself for your own or your organisation’s use? Is it any different? I suggest not and suggest that you become your own client. This paper outlines my creative process and some technical information about how I photograph trees for myself and for my clients. I believe anyone who needs to capture images of trees should strive to do the best they can. I trust the contents of this paper will help you.

Introduction
In this paper I discuss my creative approach to tree photography and the equipment and technical approaches that I use. Like all art, much of what I do is subjective. However, if I am shooting a commission for a client then there are boundaries, processes and expectations that must be honoured and met. In this paper I set out in order how a typical commission usually runs. If you are in the tree industry, please think about how my approaches might be adopted for your use if you are required to create images of trees for yourself or your organisation. I submit that even if you are creating a tree image with your phone for species ID or reporting purposes only, you can create lovely images with a little planning and understanding of what makes a great image and not just a snapshot.

What portrait do you want?
I believe that creating a great image of a tree is no different to creating a great portrait of a person. The portrait client usually has a good idea of what they want. A portrait could be a headshot, full body, close up detail, full length body shot or a smaller picture in a certain location. It is no different with trees. The choices are pretty clear: a tightly cropped full tree portrait from the ground to the top of the canopy and no other distractions (Figure 1), or a portrait of the canopy only (headshot). Other options include close ups sowing details of leaves, bark, buds, flowers, seed pods, cones etc.

Figure 1: Eye-level portrait of a Eucalyptus camaldulensis
Once I decide what the ‘portrait’ is I begin to consider the angle. In the case of trees it may be at eye level, a worm’s eye view up the trunk to the canopy (Figure 2) or top down if I can get some elevation (or use a drone). These are the issues I discuss with my clients and I suggest you also consider these if shooting just for yourself. My experience with people in the tree industry is that they usually know exactly how they want their tree to be presented. Sometimes they will say ‘you choose what you think works best’, which is fine by me of course! However, to ensure I cover all bases I will shoot as many angles and ‘portraits’ as I can so I don’t get caught short of options.

![Figure 2: Worms-eye portrait of Aracauria bidwillii](image)

**Trees in the landscape**

Sometimes I might be asked or choose to shoot a tree in its wider landscape rather than the portrait view described above. This means further reconnaissance is needed – a recce - to see how the tree trees sit in the landscape, such as in Figure 3.

![Figure 3: Streetscape with Quercus macrocarpa](image)

The first thing I do once the location is identified is to conduct a thorough recce. Unlike a human portrait a tree has many faces and they can be viewed from 360 degrees. I walk around the tree a few times to discover its most attractive face while also considering foreground and background. In urban locations surrounding
buildings and ugly structures need to be carefully considered. Once I have decided on the most suitable angle I will move on to considering light. The same recce considerations apply to a wider ‘landscape’ image.

**Composition**

Composition is very important and typically comes through a lot of experience and a ‘good eye’, which is why professional photographers will give you the best results most of the time. Factors such as leading lines, rule of thirds, patterns, textures, depth of field and symmetry will all be used if and when appropriate. Figure 4 is a good example of the use of leading lines to feature some stunning branches on this tree in a park in suburban Canberra.

![Figure 4: Leading lines to Eucalyptus blakelyi](image)

**Lighting the tree**

Having decided on the most attractive face of the tree, just like a human portrait I must decide how it should be lit to best display the natural assets it possesses. A preliminary step is to use a compass to ascertain exactly where east and west are in relation the face I wish to feature. This then allows me to discover whether sunrise or sunset would work best. As with all outdoor photography the light is best early morning or late afternoon. Figure 5 was shot late afternoon in the beautiful soft light of autumn in Namadgi National Park. My experience with trees has taught me that lower angle light works best to penetrate the canopy and light up the leaves, trunk and bark for best detail. I often want light and shadow, but high sun in the middle of the day is usually harsh and cloudy skies produce flat images. Of course there are exceptions and if I decide to do a ‘worms-eye’ view up the tree trunk to the canopy as in Figure 6 below then midday/afternoon could well work. I may decide for creative reasons to shoot with the sun at various positions such as in Figure 7. Like people, no two trees are the same and they must be treated individually as photographic subjects.
Figure 5: Great face with pleasing background Eucalyptus stellulata

Figure 6: Worms-eye view of Eucalyptus grandis

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Consider other shots

When I know how I am going to shoot the whole tree I will take a very close look at it to consider possible macro shots. For example bark, buds, flowers, seeds, cones. Some clients ask for these but even if they don’t I will probably shoot anything interesting I see to keep in my library for possible future use. While natural light is preferred I will sometimes add light to these shots to enhance the detail, especially if they are attached to the tree and in shade. Figures 8 and 9 are typical macro shots of this nature.
Planning the shoot

The weather forecast
Check the weather forecast well ahead of time and then day by day as the shoot day approaches. From my discussion about light above, you will appreciate I am generally looking for full sun days and clear weather at sunrise and sunset. Depending on the location distance from my home office, travel time also needs to be factored in, so I often leave well before sunrise. Seasons may need to come into your planning if you are capturing specific autumn foliage and or fruits, seeds, buds and flowers. Ideally wind speed should be as low as possible. I rarely shoot trees on windy days but if I have no choice then I will shoot at a faster shutter speed to stop the motion.

Plan the camera kit
I shoot exclusively with OM Systems camera bodies and lenses (formerly Olympus). For trees I typically use the E-M1X or OM-1 body and I will select a lens to suit the size of the tree and location. These are mirrorless micro 4/3 cameras but there are many full frame or cropped sensor mirrorless and DSLR bodies on the market that will do just as well. A good wide to mid telephoto lens will do the job but I often use prime lenses as they tend to be sharper. For trees I usually use a tripod and a remote trigger. This is very important if shooting high resolution at 80mpx because of the nature of the pixel shifting technology the OM System cameras use. My camera bodies do allow hand-held photography at 50mpx and the standard 20mpx is always fine in the hand as well.

Tripod choice
Tripod choice is important and I favour one that allows for 360 degree manipulation, is sturdy and has levelling built in (although I mostly use the level built into my camera). I use a Manfrotto 410 Junior Geared Head as shown in Figure 10, which does everything I need in either landscape or portrait mode. For legs I use a Manfrotto O55 which is also very robust.
**Mobile phones**

Mobile phones are useful for shooting trees and I do not discount them. If you are shooting trees purely for ID, location and reporting purposes then smartphones are ideal. Contemporary models have good quality wide angle lenses and if you follow my tips on lighting and angles you can definitely capture worthwhile images. They also have handy GPS facilities built in for recording location coordinates. If however you wish to produce high resolution artistic shots that you have full control over then a dedicated camera will do a much better job; especially if you need to produce prints for enlarging, framing and exhibiting.

**On Location**

I like to get to the location at least one hour before the time I have chosen to shoot. In photography we talk about the golden hour (one hour after sunrise and one hour before sunset) and this is my favourite time to shoot trees, all other things being equal. So I get there, setup the camera and tripod and wait for the optimum light. Figure 11 was shot at 6pm and Figure 12 at 6.30am

*Figure 11: Eucalyptus camaldulensis, a ring tree at sunset.*
Camera Settings

I shoot in RAW Format because I want to capture all the available data on the sensor for total flexibility in post production. If you are serious about shooting great tree images I suggest shooting in RAW and learning the basics of post production in Photoshop, Lightroom, or software that does not require an ongoing subscription.

Focus

I use manual focus for trees as I want to be sure exactly what is in focus. In most modern cameras there is a facility called ‘Peaking’ which I have turned on at all times. You can usually set the colour you wish and I have mine set to red. The red peaking highlights the outline of exactly what is in focus as shown in Figure 13.
Focus stacking
I sometimes use ‘focus stacking’ which is a technique designed to achieve a deep depth of field by blending (or stacking) several images together. Each stacked shot is focused in a different spot, so the combined depth of field is deeper than the depth of field produced by any of the individual images. This is particularly helpful when shooting unusual angles such as ‘worms-eye view’ up the trunk of a very tall tree or when shooting a tree in a landscape where I want the whole scene in focus from back to front.

I shoot with manual settings. In terms of the exposure triangle my ISO will be low, usually 200, my shutter speed in normal daylight will be around 1/250 s but it varies depending on the amount of light and can be a lot slower at sunrise or sunset. Shutter speed may be set higher if there is wind and the leaves are moving around. My aperture on the OM-1 will be around f5.6 or f6.3, but for full frame cameras you will probably need f8 or f11 to get the whole tree in focus. Remember there is no magic bullet for exposure as it varies with light, motion and what depth of field is required.

I shoot high resolution if I know the shot will be printed, blown up and framed for exhibition. In the OM-1 standard resolution is 20 mpx however I have the option of shooting higher at 50 mpx (handheld) and 80 mpx on a tripod. This of course produces large files; as an example Figure 14 was shot at 50mpx and as a .jpg is 10,368 X 7776 and 96.6MB. You may not be able to see it here but once enlarged and printed you will certainly see the difference.

On occasions I will shoot HDR or ‘high dynamic range’ where the I judge the difference between the highlights and shadows is just too great for a normal exposure. By shooting in Raw I know I have plenty of room to adjust exposure across the image in post production if necessary. The OM-1 comes with HDR built in, but you can also do it manually by doing several different exposures then blending them in Photoshop.

Post production
My tree images undergo very little editing. I try to get the shot as close to the end product as I can in camera. If the steps I outlined above are followed then very little post production is required. Here is my typical work flow: Raw conversion is done in DXO PureRaw where some initial sharpening and noise reduction will be applied if required. I then move the file to Adobe Camera Raw where I study my histogram and adjust blacks and whites.
to ensure correct exposure across the dynamic range. Typically I will apply ‘dehaze’ to create a little more contrast as well.

In Photoshop I will crop the frame and resize for framing if needed. Then I will remove any distracting elements such as power lines, rubbish bins, people, litter etc. I will then usually apply a subtle vignette around the subject tree to enable it to pop from the background a little more. I will then save a Photoshop file and an uncompressed .jpg. Often I will need to also create a low resolution version for sharing with clients for approval purposes.

**Conclusion**

I am passionate about photographing trees and when doing so professionally I want to take the time to deliver the best product I can for my clients. Of course you can take a ‘good’ photograph of a tree on your phone but it takes a lot of planning and skill to capture a ‘great’ artistic image of tree, particularly if it is to be enlarged, printed and framed.

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