STREET TREE PERFORMANCE IN ARID LANDSCAPES: AN ASSESSMENT OF STREET TREE PERFORMANCE AT ROXBY DOWNS

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INTRODUCTION

Increasingly we are looking for information as to better plan for the renovation of our semi-arid urban and rural streetscapes in South Australia especially to address the impact of climate change and to make informed decisions for the next 100 years. Adelaide relevant logic is simply not applicable now and we need to chart a new direction to address the future and to enable longevity of species growth. Beyond Port Augusta lies three very interesting incubators that provide significant lessons and ideas to consider, for which little research has been carried out to date and much of this knowledge is oral in its nature. These towns include Woomera, Leigh Creek and Roxby Downs that were established to service military and mining functions. Each had their own team of designers whom cared little about the respective designs, but each also had a contingent of horticulturists whom did consciously seek out comparable precedents from the three towns. This paper focuses upon recent research that has been undertaken at Roxby Downs and summarises the performance of street trees in this environment since the town was initially developed in 1981-82. The research findings paint a clear picture that a cohesive and sensitive regime of plant establishment, watering and mulching is necessary to obtain tree strike success but also that one has to be mindful of tree species and has to look beyond the South Australian landscape if one is to create an Australian landscape environment.

ROXBY DOWNS: CONTEXT

Since 2005 the town of Roxby Downs has served as a research and design inquiry incubator for students from the Master of Landscape Architecture Program at the University of Adelaide within a design studio course. This initiative has been supported by the Town Council of Roxby Downs and BHP Billiton, and directly and indirectly by staff from these organisations together with staff from the City of Port Augusta, the City of Port Pirie, TAFE SA and the University of Adelaide. The goal of this initiative has been to foster and enhance student appreciation and understanding of arid ecological planning and design issues. Coincidentally the University, through its School of Earth & Environmental Sciences, has been a direct partner in the internationally significant Arid Recovery Project just north of Roxby Downs. Further, while this initiative commenced prior to the current Olympic Dam Expansion Environmental Impact Assessment investigation, it has been instrumental as a testing ground for town design and planning thoughts and strategies for both the Council and BHP Billiton to ponder and reflect against the ideas and arguments of their own consultants.

Variables of town planning, urban design, 'construction' of Development Plans and zone provisions, streetscape and general landscaping, ecological performance and biodiversity enhancement, ecological vulnerability risk assessment, and horticultural performance have all been part of this inquiry. Interestingly, climate change has only begun to be a variable in the last 2 years but much of the climatic context of Roxby Downs is determined, continues to be determined, and will be determined by its arid setting characterised by high daily temperatures, low night temperatures, variable wind patterns, and increasing arid rainfall deluges. One would not perceive that flooding is a problem in Roxby Downs but it was thankfully very much a concern in the original engineering and spatial design of the town and this expectation continues today.

As part of this inquiry a suite of research questions and problems have been progressively raised, tested, modelled, and pondered. The most relevant to TREENET is street tree performance. In particular, given the context and experimental nature of Roxby Downs as one of several testing grounds for arid zone street trees, and in light of its current expansion expectations and the larger debate about climate change, what has been street tree performance in Roxby Downs and what relevance does it have to the arid zone *per se* but importantly to the peri-arid zones like with the Northern and Yorke Peninsula NRM region that is facing a similar climatic setting in the next 50 years.

This paper summarises a research project instigated by this larger inquiry, and led by Master's student Jessica Bennett in 2006, whom now works for Mt Isa City Council and is involved in landscape design and street tree futures for this peri-arid zone municipality.

ARID LANDSCAPE DESIGN IN AUSTRALIA

"In the past with a few notable exceptions, the design and development of these remote arid townships has had little regard to climatic conditions and appropriate landscaping has more often than not been overlooked" *State Minister Don Hopgood (Den Ouden et al, 1983, p.1)*

Contemporary academic and professional literature concludes that residents in arid Australia are faced with finite quality and quantity water resources, poor soils to nurture plant life and that the surrounding physical and climatic environment has a significant effect on the quality of life for isolated residents. While this research project did not focused upon residents and their aesthetic values towards street trees, it is very evident that this aspect cannot be ignored in the larger discussion. As John Zwar has written, "appropriate landscaping helps ameliorate the vast expanse of the harsh Australian outback that some people find oppressive and monotonous" (Zwar, Jones 2003, p.4)

Further, communities residing in remote arid towns have additional social and psychological pressures and issues associated with their isolation and surrounding environment. It is also very evident that well planned landscaping can have beneficial psychological effects upon a community faced with these issues. Accordingly, street trees should be viewed as an integral part of the urban infrastructure and its design, thereby an asset in arid settlements, and not

just a superfluous 'greening' agenda with a minuscule budget thought about at the end of a construction project. In preparing a siting and design guideline document for South Australian arid communities in 1983, architect Henk Den Ouden who was previously chief architect for the Monarto Development Commission, concluded: "It is particularly important for town landscaping to be well designed and well maintained as it affects the co-operativeness and sense of well being of the community" (Den Ouden et al, 1983 p. 41).

Paramount is that educated planting design with careful use of water and plants will help reduce soil erosion, saltation, weed problems and protect native habitats. To ensure success of the plant and tree establishment and growth in arid settlements the following principles have been concluded as the best strategy to follow:

In terms of plant species selection:

- plant species should be selected for their low water requirements
- special consideration must be given to soil type and the micro climate
- endemic species found locally are best suited for use in arid landscape design and should be prioritised over imported indigenous species
- where water requirements are adequate, which should be philosophically non-existent in arid zones, exotic species can be included as feature plants
- plant species selected should have the desired characteristics of size, strength, shape and colour relevant for the planting purpose
- plant species should seek to address and provide relief from the extremes of heat, low humidity and dust by creating shade and reducing wind speeds
- planting design should also seek to reduce soil erosion, saltation and minimize weed introduction, transmission and consequential problems
- recognition must be made that some native plants can become weeds in other parts of the Australian continent, and
- endemic plant species generally thrive without expensive soil amendments.

In terms of watering practices:

- endemic plants require irrigation to enable their establishment
- drip irrigation systems is the most effective way of watering plants in hot arid environments
- night time watering is recommended to reduce evaporation losses by up to 50%, and day watering should be very limited
- if watering is done during the day, the hottest part of the day should be avoided, with watering in the early morning or late afternoon
- following initial tree establishment, infrequent deep watering is preferable to encourage deep strong root growth
- after the first summer of planting, when the trees are established, watering can be tapered off gradually to four deep soakings per year and may include running drip irrigation systems for 48 hours

In terms of water harvesting practices:

- water harvesting should maximise the use of rainfall by capturing and directing run-off from roofs and hard surfaces
- grassed swales should be included along roadside verges help to redistribute excess stormwater to public planting areas where soil infiltration can occur
- consider should be given to using treated sewage effluent and grey water as sources of irrigation water

In terms of surface mulching:

- surface mulching should be applied as it educes moisture loss, erosion and controls weed growth
- for surface mulch to be effective it should be 100 to 150mm deep
- ground cover plants can act as living mulch

In terms of soil preparation:

- soils in the arid region are low in organic matter composition
- the use of synthetic materials in sandy soils will retain moisture
- the use of organic matter such as compost will increase soil fertility, improve soil water holding ability and reduce soil alkaline content
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In terms of existing vegetation:

- existing vegetation retention helps prevent soil erosion and dust problems during any construction phase
- existing vegetation will also continue to provide a home for local birds and wildlife, thereby biodiversity enhancement, and provide solar and wind shelter for new plantings

The above were strategies and actions relevant to arid landscape design were specifically based upon the following research:

- 'Water and landscape design in arid environments' in the BDP Environment Design Guide DES 54 by Jones and Zwar (2003).
- 'Water sensitive landscape design in arid environments', an unpublished honours thesis by Nicholas Pearson that includes case studies on Broken Hill, Leigh Creek and Woomera (Pearson, 2004).
- 'Development Guide for Arid Areas in South Australia' produced by the Department of Environment and Planning (Den Ouden et al, 1983).
- Detailed case studies of Leigh Creek by Christopher Wren and Andrew Beal (Wren, 1987 and Beal, 1991).

The conclusions in this literature point to a clear set of strategies and actions that can be applied to any landscape development in the arid zone in particular to watering, plant establishment, soils and mulching practices. These recommended practices will assist in water conservation and locating, establishing and maintaining vegetation. It has been stated in much research that species selection is important, however most of this research does not provide details as to specific tree species and how they can be used successfully in a streetscape.

ROXBY DOWNS: TOWN HISTORY

Roxby Downs is located approximately 500km north of Adelaide in South Australia's hot arid zone. Western Mining Corporation (WMC) began mineral exploration in the Olympic Dam area for copper deposits in 1972. Following a series of feasibility studies and government approvals, mineral excavation and production at Olympic Dam commenced in 1988 (Kinhill Engineers, 1997). WMC has recently been acquired by BHP Billiton.

To service the Olympic Dam mine development, the Roxby Downs township was developed from 1985 onwards some 11km south of the Mine. As the mine developed in phases, so did the town. The second phase expansion was paralleled by a large expansion of the town in 1997. This research study summation focuses upon street tree plantings in the northern portion of the town that was developed and planted in the 1986-1988 period. The current infrastructure and configuration of the town caters for a population of 4500, and with the prospective third phase of development the town is on the verge of another expansion that may increase its population to approximately 10,000.

ROXBY DOWNS: CLIMATE

As we have all heard, 'South Australia is the driest state in the driest continent in the world'. The climate at Roxby Downs is very hot in summer and mild to cool in winter. During summer, day temperatures often exceed 40^{o}C with night time temperatures remaining high. During winter, days can be quite warm, however, night time temperatures can fall below 0 ^{o}C (Den Ouden *et al*, 1983, p 5). The humidity is highest in winter and temperatures highest in summer.

In terms of tree establishment the best times to plant specimens, having regard to the local seasonal weather conditions, is in mid to late autumn (April to May). During April to May temperatures are still relatively warm, but not hot as to detrimentally affect plant health as would occur in the peak temperatures over summer (the worst time to plant). In addition, April tends to have a reliable cool weather phase in advance of winter and evaporation rates during this month tend to be not excessive. This enables newly planted trees some six months of establishment before the hot, dry weather onslaught of the next summer.

ROXBY DOWNS: REGIONAL ENVIRONMENT

The landforms of the surrounding Roxby Downs region are composed of regular east-west lineal sand dunes with interdunal corridors (swales). These sand dune areas can be divided into two characteristic groups of endemic vegetation species; those species that prefer deeper sands along the dune ridges and those species that require more structured soils within swales. The boundary between these two environments is not always distinct because the depth of the sand and organic matter varies over surfaces and the larger dunal landscape. These dunal fields are generally dominated by an open *Acacia* spp dominated woodland on sand dune ridges, and by a *Chenopod* spp dominated shrubland on the structured soils of interdunal corridors.

ROXBY DOWNS: HYDROLOGY

Rainfall in Roxby Downs is not reliable as a regular source of water. "The depth of water penetration into the soil is often poor and high day temperatures mean evaporation levels are very high" (Den Ouden *et al*, 1983, p. 5). With high average evaporation (3000mm per annum) and low average rainfall (150mm per annum) soil moisture content is low in Roxby Downs. Further, the sand dune ridges have infiltration rates during rainfall events while the swales are relatively impermeable resulting in ponding and flash-flooding (Kinhill Engineers, 1997, Ch. 3, p. 2). The dearth of young trees around Roxby Downs and adjacent regions is largely due to low rainfall events over the past century that been insufficient in their volume and soil penetration (Read, 2003, p. 20).

ROXBY DOWNS: SOILS

The most important ingredient in determining local vegetation communities is soil (Read, 2003, p. 13). The north-western section of Roxby Downs town was consciously excavated to enable the construction of a residential area in 1987/88 thereby removing the surface dunes and exposing the underlying clay soils. The remaining portion of the study area researched was constructed on top of the existing sand dunes and swales that were not excavated. The sand dune formations at Roxby Downs are composed of siliceous sand, while the swales are loamy or clayey in their composition, with a variable gibber stone coating, or are covered by thin sand sheets (Kinhill Engineers, 1997, Ch. 3, p. 2)

To the south of Roxby Downs, the soils shift towards flat gibber plains visually prevalent around Woomera, and seldom sustain tree growth. This is due to the fast water runoff over clay soils that dry rapidly after rains. In contrast, the deep sands around Roxby Downs can store water like a sponge, allowing larger and long-lived plants to establish (Read, 2003, p. 13). Despite this, the removal of the deep sands in the northern portion of the town to enable residential development can and has affected the water storage capabilities of this soil.

Soil types within the Roxby Downs township comprise:

- "sandy clay soils of low to medium plasticity, becoming very silty or gravely at depth"
- "clay soils of medium to high plasticity showing gradational profile or weak texture contrast; a thin surface veneer of coarser texture may occur locally; often stratified layers of coarser texture and gypsum in the lower parts of the profile" (Woods and Forests, 1986, App. C)

ROXBY DOWNS: MAINTENANCE AND WATERING PRACTICES

As part the northern area residential development, permanent drip irrigation systems were installed at the same time as plantings by contractors in 1987/1988. The contractors used poly-pipe buried at a depth so it was not exposed to or heated by the sun, with 2 drippers for a surmised big tree and 1 dripper for a surmised small tree given that certain assumptions were drawn at the time that tree species growth would correspond with past arid zone research, horticultural expectations, and 'what the experts' believed would occur. The corresponding maintenance and watering regimes for these and later street tree plantings were carried out by a consulting company 'Outback Landscaping.' The irrigation system installed comprised both manual and automatic systems in different sections of the street reserves or verges. Manual systems were originally applied once a week, running for 4 hours at 7.30am and 1pm. Automatic systems were battery powered enabling watering from 10am-4pm every second week day and were not operated on weekends. The manual systems ceased operation in 2004 and the automatic systems last had their batteries replaced in 2005. As a consequence, it is quite possible that some trees species are experiencing stress after the loss of regular watering of their root systems and that many have become accustomed to this change of watering regime (pers. comm. Boehm, 2006).

A key problem in tree establishment and watering regime success was damage caused to these irrigation systems by vehicles, tree roots and additional residential construction works such as changes to driveways. While the irrigation systems were believed to have been checked every six months for leaks the actual level and location of irrigation system damage was not monitored nor rectified in any systematic manner (pers. comm. Boehm, 2006). Specimen street trees were however pruned once a week, up to 2m above ground over footpaths and up to 4m above ground over roadways (pers. comm. Boehm, 2006).

STREET TREE PERFORMANCE RESEARCH

In undertaking this research project, that drew upon successive years of design inquiry by students and a investigation of Council archives, the following research questions were proposed:

- What street trees species have been the most successful, assuming to an equitable implementation and management regime, for use in arid urban environments like Roxby Downs?
- How do street trees in the residential areas of Roxby Downs perform from a horticultural perspective?
- What was the original planting scheme for the Roxby Downs streetscapes, has it been successful, how has this changed and modified with new knowledge and retrospectivity, and how has appreciation affected street tree growth performance?
- What is the current care/ maintenance regime of street trees in Roxby Downs?
- What external factors have influenced the performance of the street trees in Roxby Downs?

RESEARCH METHODOLOGY

This conference paper summarises the research findings as to streetscape performance of trees within the town of Roxby Downs, an arid mining town in South Australia.

Due to research time constraints for data collection, this project did not consider the aesthetic value of trees. Instead it focused upon street tree performance from a horticultural perspective. The research involved audits of trees within a number of streets of Roxby Downs. Time did not permit for a detailed study of all streets in Roxby Downs, so a number of streets were selected as case studies to model and assess street tree performance in the town overall. Each street was therefore a case study within the larger dynamic environmental context of Roxby Downs.

As a consequence, the research methodology involved in-depth examination and survey of ten selected residential streets within Roxby Downs with tree plantings undertaken between 1987-1988. The selection of streets was based upon the following criteria:

- portions of streets had to be of a reasonable length;
- overall street selection had to give a good geographical spread; and,
- streets had to possess a reasonable cross section of vegetative specimen types (based on information provided by Council and visual analysis)

Accordingly, the following residential streets were selected:

- Blanche Court
- Burgoyne Street
- Curdimurka Street
- Hermit Street
- Kennebery Crescent
- Mulgaria Crescent
- Nyaroo Court

In terms of these selected streets, 416 street trees were surveyed and 41 tree species were identified. The sample size for each species varied from 62 to 1. Significant conclusions can only be made from data with a reasonable sample size. Accordingly, the results for tree species with 2 samples or less were discounted in the overall analysis.

Table 1 : Averages Per Species (table sorted by overall tree condition and number of samples per species)

Genus/Species	No.	Overall Tree Condition	Avg. Score	Avg. Height	Avg. Width (Diam)	Max.Trunk Circumf	Avg. Dieback	Avg. Deadwood	Avg. Fungal attack	Avg. Insect attack	Avg. Tree Rot	Avg. Trunk Damage	Avg. Vigour	Avg. Crown Shape
Eucalyptus brockwayi	35	Good	4.77	8.43	5.63	0.63	0.17	0.14	0.00	0.00	0.03	0.06	0.14	0.03
Eucalyptus salubris	25	Good	4.88	9.00	6.26	0.71	0.16	0.20	0.00	0.00	0.00	0.08	0.12	0.00
Eucalyptus stricklandii	11	Good	4.82	9.09	6.82	0.78	0.18	0.18	0.00	0.00	0.00	0.00	0.00	0.00
Eucalyptus platypus	8	Good	4.63	5.75	4.44	0.38	0.38	0.50	0.00	0.00	0.00	0.13	0.13	0.00
Eucalyptus salmonophloia	7	Good	4.86	8.57	5.43	0.60	0.14	0.43	0.00	0.00	0.00	0.14	0.14	0.00
Eucalyptus camaldulensis	6	Good	5.50	13.67	7.67	1.22	0.17	0.17	0.17	0.17	0.00	0.00	0.00	0.00
Casuarina decaisneana	6	Good	4.51	8.00	1.33	0.35	0.17	0.00	0.00	0.00	0.00	0.00	0.17	0.00
Eucalyptus socialis	5	Good	4.60	5.80	3.60	0.34	0.00	0.00	0.00	0.00	0.00	0.00	0.40	0.00
Eucalyptus campaspe	4	Good	4.75	9.75	6.25	0.65	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Acacia ligulata	3	Good	4.67	3.67	5.00	0.33	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Callistemon 'Harkness'	2	Good	5.00	4.00	3.00	0.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eucalyptus torquata	2	Good	5.00	6.50	6.00	0.68	0.00	0.00	0.00	0.00	0.00	0.50	0.00	0.00
Melaleuca lanceolata	2	Good	5.00	2.00	4.00	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eucalyptus cladocalyx	1	Good	5.00	13.00	10.00	0.72	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eucalyptus papuana	1	Good	5.00	9.00	5.00	0.51	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eucalyptus petiolaris	1	Good	5.00	8.00	7.00	0.83	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eucalyptus woodwardii	1	Good	5.00	8.00	4.00	0.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eucalyptus youngiana	1	Good	5.00	3.00	4.00	0.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Genus/Species	No.	Overall Tree Condition	Avg. Score	Avg. Height	Avg. Width (Diam)	Max.Trunk Circumf	Avg. Dieback	Avg. Deadwood	Avg. Fungal attack	Avg. Insect attack	Avg. Tree Rot	Avg. Trunk Damage	Avg. Vigour	Avg. Crown Shape
Eucalyptus intertexta	62	Good-Fair	4.23	9.08	5.11	0.65	0.47	0.44	0.11	0.03	0.02	0.08	0.31	0.06
Eucalyptus erythronema	25	Good-Fair	4.28	7.52	4.84	0.46	0.60	0.60	0.04	0.00	0.00	0.00	0.24	0.04
Acacia aneura	20	Good-Fair	4.05	3.85	3.00	0.18	0.30	0.20	0.10	0.05	0.00	0.20	0.40	0.05
Eucalyptus microtheca	20	Good-Fair	3.95	7.30	4.30	0.48	0.60	0.50	0.00	0.05	0.00	0.00	0.35	0.00
Acacia papyrocarpa	19	Good-Fair	4.11	2.79	2.97	0.23	0.37	0.42	0.32	0.32	0.00	0.16	0.11	0.11
Eucalyptus sargentii	14	Good-Fair	4.21	8.79	7.64	1.11	0.29	0.14	0.00	0.00	0.07	0.21	0.07	0.14
Eucalyptus eremophila	4	Good-Fair	4.49	3.00	2.75	0.19	0.00	0.25	0.00	0.00	0.00	0.00	0.00	0.00
Eucalyptus gillii	2	Good-Fair	4.00	4.50	2.50	0.26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50
Acacia cambagei	1	Good-Fair	4.00	4.00	3.00	0.20	1.00	1.00	0.00	0.00	0.00	0.00	1.00	0.00
Eucalyptus leucoxylon	1	Good-Fair	4.00	7.00	4.00	0.28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eucalyptus occidentalis	1	Good-Fair	4.00	6.00	4.00	0.72	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00
Santalum acuminatum	1	Good-Fair	4.00	2.00	2.00	0.33	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00
Callitris glaucophylla	66	Fair	2.65	5.05	2.15	0.27	1.09	0.80	0.09	0.03	0.00	0.09	0.89	0.18
Acacia estrophiolata	19	Fair	3.37	6.95	4.53	0.29	0.95	1.05	0.00	0.00	0.05	0.21	0.79	0.11
Acacia pendula	14	Fair	3.43	5.46	3.46	0.30	0.64	0.71	0.00	0.00	0.00	0.14	0.64	0.07
Eremophila oppositifolia	8	Fair	3.00	2.56	2.31	0.17	1.25	1.88	0.00	0.00	0.00	0.00	0.88	0.00
Acacia salicina	5	Fair	3.00	4.90	3.80	0.31	0.80	1.00	0.40	0.40	0.00	0.00	0.60	0.00
Melia azederach	3	Fair	3.33	6.00	5.00	0.48	0.67	0.67	0.00	0.00	0.00	0.00	0.33	0.00
Casuarina pauper	2	Fair	3.00	4.00	3.50	0.22	0.50	1.00	0.00	0.00	0.00	0.50	0.50	0.00
Eucalyptus albopurpurea	2	Fair	3.50	4.50	4.50	0.21	0.50	1.00	0.00	0.00	0.00	0.00	0.50	0.00
Eucalyptus leptophylla	2	Fair	3.50	5.00	4.50	0.20	1.00	1.00	0.00	0.00	0.00	0.00	1.00	0.00
Eucalyptus 'Torwood'	2	Fair	3.50	4.50	4.50	0.36	1.00	0.50	0.00	0.00	0.00	0.50	0.50	0.00
Acacia longifolia	1	Fair	3.00	6.00	4.00	0.39	0.00	1.00	1.00	0.00	0.00	1.00	0.00	0.00
Eucalyptus sp.	1	Poor	1.00	6.00	4.00	0.33	2.00	2.00	0.00	0.00	0.00	0.00	1.00	0.00
Grand Average	**416**	**Good-Fair**	**3.99**	**6.84**	**4.38**	**0.47**	**0.53**	**0.49**	**0.06**	**0.04**	**0.01**	**0.09**	**0.38**	**0.06**

CONCLUSIONS

This research identified street tree performance of specimens found in ten selected streets in Roxby Downs. While other tree species may also have been successful in arid environments similar to those of Roxby Downs they were not addressed in this study. The majority of the street tree species studied were endemic to arid Australia and exhibited adaptations that increased their survival under the difficult conditions. Therefore, it was concluded that most of the trees selected were appropriate for use in arid conditions, however some performed better than others.

The tree species identified in the following tables display more specific information as to the varying successfulness of the species using a rating system of 'Fair' to 'Good' in the current environmental and maintenance conditions of Roxby Downs. It needs to also recorded that from 2004 the majority of all street trees in Roxby Downs received little or no irrigation (pers. comm. Boehm, 2006). Accordingly, it is conceded that the results overall may have differed if the plant specimens had been subject to continuous and regularly watering, considering many of the species are endemic to regions which have a higher annual rainfall than Roxby Downs. Notwithstanding this, it is important to note that all specimens were subject to regular watering during their establishment phase. Because of this historical regime, it is possible that some species are now in stress due to the absence of regular watering over the last few years.

AVERAGE RESULT: GOOD- FAIR

The following table summarises street tree species with reasonable sample size that performed 'Good-Fair' overall. The species have been arranged in order of height. Arising from these results, these trees are recommended as first preference street trees for use in existing street verge planting operations in Roxby Downs, or in future street tree planting actions, or in arid regions with similar climatic conditions, subject to the following conditions:

- That the trees receive adequate watering (four deep soakings year) during their establishment phase
- That the trees are planted in soils in which they are naturally found, or in modified soils.
- That the trees are well mulched to minimise evaporation.

Species	Avg. Height	Avg. Width (Diam)	Max.Trunk Circumf
Eucalyptus camaldulensis	13.7	7.7	1.22
Eucalyptus campaspe	9.8	6.3	0.65
Eucalyptus stricklandii	9.1	6.8	0.78
Eucalyptus salubris	9.0	6.3	0.71
Eucalyptus salmonophloia	8.6	5.4	0.60
Eucalyptus brockwayi	8.4	5.6	0.63
Casuarina decaisneana	8.0	1.3	0.35
Eucalyptus socialis	5.8	3.6	0.34
Eucalyptus platypus	5.8	4.4	0.38
Acacia ligulata	3.7	5.0	0.33

AVERAGE RESULT: GOOD

The following table summarises street tree species with reasonable sample size that performed 'Good' overall. Due to these results, these street tree species are recommended for use as successfully performing street trees in Roxby Downs or arid regions with similar climatic conditions. The species performed well without additional watering receiving minimal irrigation since 2004. This indicates that these street tree species can still perform well under natural rainfall and non-porous surface runoff conditions, and would be good street tree species for use in areas with low rainfall, requiring little additional water. The species have been arranged in order of height.

Species	Avg. Height	Avg. Width (Diam)	Max.Trunk Circumf
Eucalyptus intertexta	9.1	5.1	0.65
Eucalyptus sargentii	8.8	7.6	1.11
Eucalyptus erythronema	7.5	4.8	0.46
Eucalyptus microtheca	7.3	4.3	0.48
*Acacia aneura**	3.9	3.0	0.18
Eucalyptus eremophila	3.0	2.8	0.19
Acacia papyrocarpa	2.8	3.0	0.23

AVERAGE RESULT: FAIR

The following table identifies the street tree species with reasonable sample size that performed 'Fair' overall. These species are not ideal in arid environments, however could be used in appropriate circumstances where the following conditions are met:

- That the street trees receive adequate and a continuous regime of watering (more than four deep soakings year, plus additional watering)
- That the street trees are planted in soils with consistency and pH in which they are naturally found, or in comparable modified soils.
- That the street trees are effectively mulched to minimise evaporation.
- That their performance is monitored, receiving additional pruning/ water if necessary

Species	Avg. Height	Avg. Width (Diam)	Max.Trunk Circumf
*Acacia estrophiolata**	7.0	4.5	0.29
Melia azederach var *australasica*	6.0	5.0	0.48
Acacia pendula	5.5	3.5	0.30
*Callitris glaucophylla**	5.1	2.2	0.27
*Acacia salicina**	4.9	3.8	0.31
*Eremophila oppositifolia**	2.6	2.3	0.17

KEY RECOMMENDATIONS

While the above summation results indicate which street tree species performed well in the arid conditions of Roxby Downs, the following ingredients have been concluded essential in enabling their growth to reach their desired size and growth, and to continue to perform desirably.

- *establishment*: the best times to plant are in mid to late autumn (April to May). At this time the temperature is still warm, but not too hot as to be detrimental to plant health. This gives trees a chance to establish before the hot, dry weather of the next summer. New plants should receive weekly irrigation for 4-6 hours.
- *deep watering:* avoid short and light applications of water on the surface as it will result in high evaporative water losses, and surface rooting habits. Infrequent deep watering is preferable (Den Ouden *et al*, 1983, p. 50). After the first summer, when the trees are established, watering can be tapered off gradually to four deep soakings per year (run drip irrigation for 48 hours). This may need adjustment in severe drought (Jones & Zwar, 2003, p. 9).
- *protection of plants:* small tubed seedlings should be used due to their ability to adapt. Nursery specimens should be raised in a similar climate to where they will be planted. The soil should be wetted prior to planting.
- *irrigation:* It is essential for water to penetrate into the soil to encourage a deep strong root growth very quickly to give new trees a good chance of survival. Trees with deep roots are less vulnerable to high temperatures and evaporation (Den Ouden *et al,* 1983, p. 51). Drip irrigation systems are the most effective way of watering plants in the arid zone (Jones & Zwar, 2003, p. 9). The number of drippers and volume of water for each plant can be varied. Night time watering is recommended, reducing evaporation losses up to 50%. If watering must be done in the day, the hottest part of the day should be avoided, watering in the early morning or late afternoon (Pearson, 2004, p. 22).
- *mulch:* mulching should be used to reduce evaporation, protect the root system of young plants, conserve moisture in the soil and control weed growth (Den Ouden *et al*, 1983, p. 50). A depth of 100-150mm is desirable (Jones & Zwar, 2003, pp3).
- *soil preparation***:** soils in arid regions are generally low in organic matter. Soil improvements can assist in enabling a wider choice of plants. However it is often possible to achieve excellent results with minimal soil amendment if appropriate species are chosen. The use of synthetic materials in sandy soil will retain moisture. Organic matter such as compost will increase fertility, improve water holding ability and reduce alkaline content. The use of fertilisers for broadscale planting is not generally recommended (Den Ouden *et al*, 1983, p .53).

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Table 1: Street Tree Species and Distribution list for 10 surveyed streets in Roxby Downs

Genus/Species	Common Name	Distribution
Acacia aneura	Mulga	Widely distributed over the inland arid areas of Australia. Occurs on a variety of soils.
Acacia cambagei	Gidgee, Stinking wattle	Widespread in Qld and in north- western NSW, the Cooper basin and from Peake northwards on the Oodnadatta track. Also in low open woodland in the Lake Eyre region of SA and NT.
Acacia estrophiolata	Ironwood	Restricted to central Australia, particularly to sandy red earths south and east of Alice Springs. Patchy distribution about Barrow creek in the NT.
Acacia ligulata	Umbrella bush	Widespread across Australia, occurring mostly south of the Tropic of Capricorn, frequently on the lower slopes of sand dunes.
Acacia longifolia	Sallow wattle	Mostly on coastal side of Main Divide, east tablelands in NSW, also Grampians and SA.
Acacia papyrocarpa	Western Myall	Restricted to arid and semi-arid regions on sandy loams and calcareous soils in the north-western, Lake Eyre, Nullarbor, Gairdner-Torrens, Eyre Peninsula and Flinders Ranges of SA and also the south-east of WA
Acacia pendula	Weeping Myall	Common in NSW Riverina and northward, often on clay based soils
Acacia salicina	Broughton Willow, Native Willow	Scattered, especially on heavier soils along inland waterways and also sandy sites with mulgas.
Callistemon 'Harkness'	Bottlebrush	Cultivar hybrid, propagating from cuttings. Thrive in both the cooler areas of Victoria as well as the hot towns in the Mallee.
Callitris glaucophylla	Native pine, White cypress pine	Common in inland Australia. Grows naturally in Roxby downs region.
Casuarina decaisneana syn. *Allocasuarina decaisneana*	Desert Oak	Lower slopes and swales in central Australia, ranging from near Billiluna at the northern end of the Canning Stock Route to between the Mann and Musgrave Ranges in SA
Casuarina pauper	Black Oak	Ranges from central NSW west of Bourke, across SA to central WA.
Eremophila oppositifolia	Weeooka, Twin-leaf Emubush	Scattered on red-brown sandy loams of SA Murray Lands and northward, also spreading to central NSW & Qld
Eucalyptus brockwayi	Dundas mahogany	Scattered distribution around Norseman; endemic to WA
Eucalyptus camaldulensis	River Red Gum	Widespread around Australia, typical habitat wet or dry watercourses. Due to the level of information available the sub-species cannot be quantified
Eucalyptus campaspe	Silver Gimlet	Restricted distribution in the central goldfields, particularly around Coolgardie and southwards, favouring stony rises; endemic to WA
Eucalyptus cladocalyx	Sugar Gum	Restricted to four disjunct localities, southern Flinders Range to north-west of Quorn, Kangaroo Island and two localities on Eyre Peninsula; endemic to SA
Eucalyptus eremophila	Sand Mallee	Widespread in the wheatbelt and goldfields of the south-west, extending to east of Zanthus and south to the coastal plains; endemic to WA
Eucalyptus erythronema	Red-flowered Mallee	Southern wheatbelt, east towards Southern Cross; endemic to WA
Eucalyptus gillii	Curly Mallee	Disjunct distribution in the northern Flinders Range of SA and Barrier Range north of Broken Hill, NSW
Eucalyptus intertexta	Gum-barked Coolibah	Scattered occurrence in SA north of the River Murray, the northern Flinders Range, northern Eyre Peninsula and further inland and in the eastern part of the Great Victoria desert in WA (south-west of Worburton)
Eucalyptus albopurpurea syn. *Eucalyptus lansdowneana* var. *leucantha*		Kangaroo Island and southern Eyre Peninsula; endemic to SA
Eucalyptus leptophylla	Narrow-leaved red Mallee	From the eastern goldfields of WA eastwards to SA, north-western Victoria and central NSW, particularly in the sandy areas, also foothills of the Mount Lofty Ranges
Eucalyptus leucoxylon	South Australian Blue Gum	Widely distributed on the plains and nearby ranges of coastal SA; also in Victoria
Eucalyptus microtheca	Coolibah	Found near inland watercourses, Darling River north of Menindee and northern SA. Heavy alluvial soils.
Eucalyptus occidentalis	Swamp Yate	Southern wheatbelt and subcoastal areas from the western part of the southern wheatbelt to Cape Arid National Park in the east; usually confined to wet clayey depressions; endemic to WA
Eucalyptus papuana syn. *Corymbia aparrerinja*	Ghost Gum	Occurs from arid to monsoon tropical areas of WA, NT, Qld. Distribution extends from central Aust. north to Tennant Creek, in red sandy soils, extending eastward to Cloncurry, with a separate distribution on red earths in central Qld.

Eucalyptus petiolaris	Water Gum	Scattered distribution on Eyre Peninsula in SA; endemic to SA
Eucalyptus platypus	Moort	Scattered distribution on southern coastal and subcoastal plains between Albany and Esperance, often growing in pure sands; endemic to WA
Eucalyptus salmonophloia	Salmon Gum	Widespread throughout the wheatbelt and goldfields from Morawa in the north, eastwards to near Pinjin Station and to Southeast of the Fraser Range; endemic to WA
Eucalyptus salubris	Gimlet	Widespread from the northern wheatbelt and goldfields eastwards to the western part of the Great Victoria Desert and southwards to the Fraser Range, often occurring on plains and depressions; endemic to WA
Eucalyptus sargentii	Salt River Gum	Limited and scattered occurrence in the wheatbelt from west of Meckering and particularly in the Quairading, Tammin, Hines Hill, Hyden area, but extending to near Binnu and Eurady in the north and southwards to Pingaring, found near salt lakes; endemic to WA
Eucalyptus socialis	Red Mallee	Widespread distribution in the mallee scrub of NSW, Victoria and SA, in the Pilbara district of WA on both the plains and mountain tops, also on the sandy plains of the upper Gascoyne River channels and in the Great Victoria Desert; often on limestony rises
Eucalyptus stricklandii	Strickland's Gum	Scattered distribution south and east of Coolgardie and Kalgoorlie towards Norseman, and eastwards towards Zanthus, one disjunct occurrence between Menzies and Diemals; endemic to WA
Eucalyptus torquata	Coral Gum	Scattered distribution in the central and southern goldfields, from Coolgardie to South of Norseman also east of Kalgoorlie, usually on rises; endemic to WA
Eucalyptus 'Torwood'	Hybrid Coral Gum	Hybrid of E. torquata & E. woodwardii from WA
Eucalyptus woodwardii	Lemon-flowered Mallee	Very restricted distribution, only a few sites east of Karonie; endemic to WA
Eucalyptus youngiana	Yarldarlba	Scattered and widespread distribution from north of Kalgoorlie eastwards, north of the Nullarbor Plain and throughout the Great Victoria Desert in SA
Melaleuca lanceolata	Moonah	Found in south and south west of SA, NSW, Vic and WA
Melia azederach var *australasica*	White Cedar	Shoalhaven River, NSW to Cape York, Nth QLD.
Santalum acuminatum	Quandong, Desert Quandong	Widespread across southern WA, SA, Vic, NSW, and small pockets in Qld and NT.