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

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

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

Introduction

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

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

Part 1: Adelaide's climate

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

Summer

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

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

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

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

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

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

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

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

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

Climate variability, climate trends and climate change

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

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

Future climate projections for southern Australia

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

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

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

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

Part 2: Adelaide's green infrastructure

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Watering practices in open space

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

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

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

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

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

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

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

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

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

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

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

Plant selections: to lawn or not to lawn

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

Garden design

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

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

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

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

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

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

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

The aims of WSUD are to:

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

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

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

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

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

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

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

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

Conclusion

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

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

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

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