LANDSCAPE SUCCESSION STRATEGY
MELBOURNE GARDENS
2016 – 2036

ADAPTING A WORLD-RENOWNED BOTANICAL LANDSCAPE TO CLIMATE CHANGE

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ROYAL BOTANIC GARDENS VICTORIA

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Melbourne Gardens 2016 – 2036

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TO CLIMATE CHANGE
1 JULY 2016 - 30 JUNE 2036

Title
Royal Botanic Gardens Victoria
Landscape Succession Strategy – Melbourne Gardens
2016 - 2036

Adapting a world-renowned botanical
landscape to climate change
1 July 2016 to 30 June 2036

Publication Date
February 2016

Cover image
Detail of *Aeonium*, a succulent
growing in Melbourne Gardens.

Publisher
Royal Botanic Gardens Board Victoria

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Foreword

The 170-year-old Melbourne Gardens of the Royal Botanic Gardens Victoria (RBGV) is universally recognised as one of the most beautiful and stunning botanical landscapes in the world. It is home to many thousands of different plants sourced from across the globe, some of them rare and threatened, others awe-inspiring for their size, beauty or botanical curiosity.

As custodians of this living masterpiece, we must plan for not only the next few decades but for the next century and beyond. Climate change has been described as the biggest threat to our planet, and for a garden growing plants well outside their natural range, it is already a clear and present risk.

Ten years ago the Royal Botanic Gardens Victoria embarked on an ambitious project to collect, treat and distribute storm water from the catchment within and around the botanic garden. The infrastructure of wetlands filtration, a sophisticated water treatment centre and landscaping to complement and encourage improvements in water quality enhanced our international reputation in integrated water management. This Landscape Succession Strategy is a natural extension of that project, and further strengthens the organisation as a global benchmark for environmentally responsible botanic garden management.

The Royal Botanic Gardens Victoria Landscape Succession Strategy for Melbourne Gardens has been developed to adapt the landscape to the likely impacts of future climate change, dwindling water supplies, aging plant populations and plant health threats, such as biosecurity. It will guide the stewardship of the Melbourne Gardens for the next twenty years, preserving the beauty and botanical diversity of these much-loved Gardens.

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1 Executive Summary

The Landscape Succession Strategy guides the transition from existing plantings to a composition more suited to the projected climate and environmental conditions of 2090, while retaining the Gardens' heritage character, landscape qualities and species diversity for future generations. It sets ambitious but achievable targets, such as maintaining existing species diversity while proportionally increasing species suitable for the projected climate, achieving 100% of landscape irrigation needs from sustainable water sources, and using these changes to assist the community in adapting to and mitigating climate change.

1.1 Challenges
Melbourne Gardens is currently facing five significant challenges:

- Adapting to a projected climate of higher temperatures and lower rainfall
- Managing and securing water supply
- Maintaining the values of a mature, heritage landscape through this transition
- Responding to biosecurity threats from increasing globalisation and changing environments
- Managing aging built assets.

1.2 Goal
The goal of our Landscape Succession Strategy is to provide future visitors to Melbourne Gardens with a place of beauty, biodiversity and refreshing green space in a changing climatic environment. The significant task ahead is to maintain the Gardens' heritage character and to support visitor wellbeing, while transitioning the landscape using a different palette of climate-suited plant species. This is an opportunity to replace susceptible plant species with alternatives that possess the necessary resilience to thrive in a future climate.

1.3 Strategies and targets
To achieve this goal we have developed the following strategies and identified accompanying targets. Focussing on these strategies and meeting these targets will ensure the transition to a more viable, resilient and thriving green space for future generations of Melburnians.

Strategy 1: Actively manage and transition the Melbourne Gardens landscape and plant collections
Target: By 2036, 75% of taxa in the Gardens are suited to the projected climate of 2090.

Strategy 2: Establish a mixed-age selection of plants composed of a diversity of taxa
Target: By 2036, plant diversity is equal to or greater than 8,400 distinct taxa of mixed-age with greater than 35% wild provenance-sourced plants.

Strategy 3: Maximise sustainable water availability and use
Target: By 2020, 100% of landscape irrigation needs are provided by sustainable water sources.

Strategy 4: Maximise the benefits of the green space and built environment through landscape design
Target: Improve green and built infrastructure capable of mitigating and withstanding predicted climatic extremes.

Strategy 5: Improve understanding of the impacts of climate change on botanical landscapes
Target: Effectively communicate with the botanical and general community on the interactions between climate change, green spaces and plant benefits.

2 Background and Context

2.1 CLIMATE CHANGE IMPACTS FOR MELBOURNE GARDENS

Climate change, along with its associated alteration of meteorological cycles and species interactions, is one of the biggest threats to Melbourne Gardens and other public gardens throughout Australia. Melbourne's future climate will be hotter and drier, with increased probability of extreme events such as heatwaves and floods. If future scenarios eventuate, with predictions of minus 15% annual rainfall and an increase of 3 °C in annual maximum temperature, the future climate of Melbourne in 2090 could be more akin to present-day Dubbo, NSW[1] (see also Appendix 2 for basis of climate analysis).

Other likely effects of climate change include alteration of competitive interactions between organisms, encouragement of invasive non-indigenous species and an increase in plant pests and pathogens, all of which may have significant impacts on the plant collections in Melbourne Gardens. In addition, climate change may influence other critical services, such as the provision of water for irrigation, which may exacerbate the effects of the environmental changes.

These changes will mean that some species that are well adapted to current environmental conditions will be less well suited to future conditions, increasing the likelihood of unacceptable performance or death. Conversely, there are other species that may perform better in future climates, which suggest the potential to source an additional suite of plants not present in current living collections, but which could be well suited to future conditions.

Figure 1 Picnickers enjoying the ambience of Oak Lawn
Photo: Jorge de Araujo

Figure 2 Climate Analogues

Figure 2 shows what towns the climate of Melbourne could be similar to by 2090 under a high-emissions scenario. Three towns are shown for comparative purposes Dubbo and Muswellbrook in New South Wales and Warwick in Queensland. Other comparative towns are Scone, Gilgandra, Condobolin, Wellington, Parkes, Forbes, West Wyalong and Cowra in NSW, and Gawler in South Australia (Information sourced from http://www.climatechangeinaustralia.gov.au/en/climate-projections/climate-analogues/analogues-explorer/) .

2.2 WHAT IS LANDSCAPE SUCCESSION?

Landscape succession is usually defined as a shift in vegetation composition and structure in response to human needs and preferences and changes in the biophysical environment. In the context of Melbourne Gardens and current climatic predictions, landscape succession could be regarded as the managed transition of a cultivated landscape from one state currently characterised by an existing palette of living plant collections to another state dominated by taxa more likely to be resilient to Melbourne's projected climate. Effectual landscape succession at Melbourne Gardens will achieve future climate suitability, maintain biodiversity, heritage and character, and provide economic, environmental, social and scientific benefits.

2.3 MELBOURNE GARDENS

For 170 years, the iconic Melbourne Gardens has been an integral part of the cultural and scientific life of the city. With its world-renowned landscape of trees, sweeping lawns and intricately planted garden beds, it has provided a place of beauty and enjoyment for many generations of Melburnians. The site extends over 38 hectares and exhibits more than 48,000 individual plants, representing over 8,400 taxa from across the world. Our living plant collections exist for the purpose of conservation, reference, research, interpretation, education and enjoyment.

Consistently attracting over 1.5 million visits per year, the demand for a green landscape within Melbourne Gardens is expected to increase with predicted climate change and with the pressures of urban population growth. Green spaces in urban environments provide vital services such as atmospheric cooling, carbon storage, stormwater remediation and opportunities for *ex situ* plant conservation. Quality green landscapes are essential for the health and wellbeing of our local community in providing places to relax, recreate and find relief from the pace of city life.[2]

If Melbourne Gardens is to preserve its heritage landscape and remain an aesthetically pleasing, healthy and resilient botanic garden in the future it is imperative we develop a strategy to mitigate the threat of climate change. Long-lived assets such as trees and the development of plant collections take many years to reach maturity. New specimens need to be selected against the criteria of future climate change and planted now to help deliver a healthy, mature future landscape that is adapted to the conditions of the future climate.

2.4 DEVELOPMENT OF THE LANDSCAPE CHARACTER OF MELBOURNE GARDENS

Ferdinand von Mueller, Director of Melbourne's Botanic Gardens from 1857 to 1873, introduced a wide diversity of plants to the collections and provided a significant contribution to the scientific reputation of the organisation in its formative years.[3] He introduced plants of both horticultural and ethnobotanical interest for use by the Melbourne colony, as well as landscape developments such as groupings of native and exotic trees, a Pinetum, and tree-lined avenues. Unfortunately, the general public became disillusioned with the resulting lack of landscape interest, which ultimately led to Mueller's dismissal in 1873.

Mueller was replaced by William Guilfoyle in 1873, who held the position of Director until 1909. Guilfoyle is credited with the design and implementation of the current picturesque layout of the landscape.

While Guilfoyle shared Mueller's views on the scientific role of the Botanic Gardens, he argued this must be balanced by visual and recreational appeal. If handled well, Guilfoyle saw no conflict between combining an aesthetic landscape tradition with a scientific role.

Guilfoyle set about an expansive remodelling of the landscape, including reorganising the avenues of trees, taxonomic groupings and individual specimens into a more picturesque style. These changes also included establishment of a simplified curvilinear path network, formation of spacious lawns and transformation of the remnant lagoon into the Ornamental Lake. All these elements combined to provide selected and significant landscape vistas. What makes the Melbourne Gardens landscape so distinctive is that Guilfolye's original vision is still largely intact today. This is a rare quality in botanic gardens around the world, and it is crucial this is maintained during implementation of the Landscape Succession Strategy.

Landscapes are often characterised by the relationship between aspects of 'mass' and 'void'. The mass comprises the foliage of the trees and shrubberies, while the void comprises the open spaces of the lawns and lakes. In Melbourne Gardens it is this mass and void relationship that creates an exceptional spatial quality. The long vistas and the serpentine curvature of the paths and lawns are also vital elements in contributing to the legacy of Guilfoyle's work. From a heritage perspective, individual plant specimens are of less relevance compared to their general contribution to plant mass in the broader landscape.

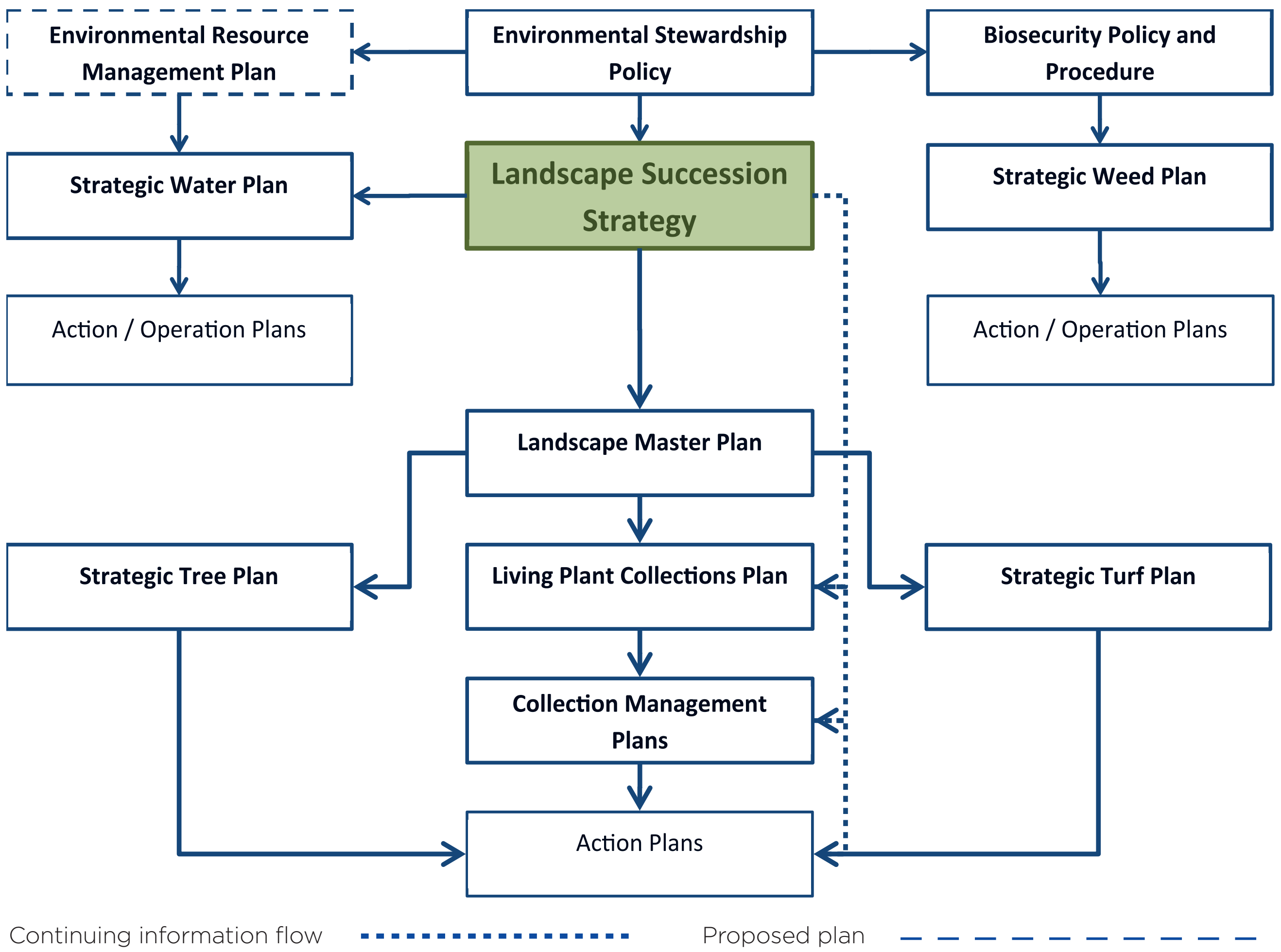
Consequently, while it is recognised that the heritage nature of the Guilfoyle-styled landscape must be conserved, there is also opportunity to replace susceptible plant species with alternatives that possess the necessary resilience to thrive in a future climate while conserving the historic character of the landscape and plant diversity. If no action is taken to transition the susceptible plantings to more tolerant taxa over a measured time period, there is an increased risk of losing plant cover from the living landscape in an unmanaged way. Responsible stewardship dictates that action must be taken to sustain a heritage and resilient landscape into the future.

Figure 3 Aerial photograph of Melbourne Gardens (the red line shows the Gardens' boundary); image sourced from Nearmap 2015, viewed 27 November http://maps.au.nearmap.com/

Figure 4 Example of a vista looking from Princes Lawn to Central Lawn – a legacy style to preserve

2.5 LANDSCAPE PLANNING FRAMEWORK OF MELBOURNE GARDENS

The diagram below illustrates the relationship of the Landscape Succession Strategy to the Royal Botanic Gardens Victoria planning and policy documents that are relevant to Melbourne Gardens. The Strategy will be implemented with full consideration to the documents that underpin and inform it.



3 Benefits of Landscape Succession

3.1 HEALTH

A warming and drying climate highlights the essential benefits that green spaces bring to the community. Historically, green open space has often been taken for granted, but contemporary thinking acknowledges that vegetated areas are as important as roads, buildings and transport in urban areas, providing an essential role in delivering social, health and wellbeing benefits to the community. Projections of current population growth for Melbourne (2.0% per annum) and trends in Melbourne Gardens' visitation suggest that by 2036 there could be 2.3 to 2.5 million visitors per annum relying on the benefits of Melbourne Gardens' cultivated landscape.[4]

Research shows that living in close proximity to green landscapes can:

- improve overall physical and mental health
- reduce incidences of family violence, and
- reduce levels of stress and depression.[5, 6]

There is considerable evidence of a strong connection between greater biodiversity (including plant richness) of green areas and an increase in psychological benefits.[7] A study of benefits for mental health undertaken in Perth found that the quality of public open space also appeared to be more important than the quantity.[8] Biodiversity and quality landscapes are elements that Melbourne Gardens already provides and these can be enhanced into the future through effective planning and implementation.

For community health, it is vital to invest now in developing and maintaining green spaces that are well-suited for the climate of the future. Increasing urban development from human population growth is deemed likely to both impact plant diversity and restrict accessibility to natural areas. In 2090, it is expected that the cultivated landscape will play an even more important role in highlighting the value of plants and connecting people to nature through its green spaces, plant collections and associated interpretation.

The intention is that visitors will still be able to find a place of beauty, biodiversity, and refreshing green space in an increasingly urbanised environment.

Figure 5 The Ian Potter Foundation Children's Garden

3.2 ENVIRONMENT

The health of vegetated spaces in the urban environment may be seen as a prime indicator of the welfare of the community that lives in its vicinity. Clean water, healthy plants and high biodiversity levels are regarded as components of a vibrant green space; protecting the landscape environment through succession planting supports continuation of these important benefits into the future.

Plant conservation and protection of distinctive plants

The Global Strategy for Plant Conservation 2011 – 2020 outlines a number of targets for improving conservation of plants. There are two targets of particular relevance to the Landscape Succession Strategy:

- Target 7 – At least 75 per cent of known threatened plant species conserved *in situ*.
- Target 8 – At least 75 per cent of threatened plant species in *ex situ* collections, preferably in the country of origin, and at least 20 per cent available for recovery and restoration programmes.[9]

There are many distinctive plant species in the living collections that already appear to be showing signs of stress from increasing temperatures or water scarcity. Programs have commenced to duplicate or transfer these taxa to other botanic gardens in Australia with more suitable climates, further strengthening *ex situ* conservation programs as the climate changes and offering greater protection to irreplaceable genetic material. Some material may also be moved to more suitable locations within Melbourne Gardens.

The more rapidly warming urban climate offers opportunities to assess how cultivated flora like the Victorian Rare or Threatened Species Collection respond to elevated temperatures ahead of similar increases predicted in natural habitats of the broader environment. Natural resource managers will be more able to effectively prioritise conservation programs.[10] Equally, tolerant cultivated plants in the living collections may be used as equivalents to identify resilient species with similar natural growing conditions. Royal Botanic Gardens Victoria has a leadership role in ensuring the effective conservation of and associated education about Victorian rare or threatened species and can facilitate this through the wider network of Victorian regional botanic gardens that have a range of microclimates.

Figure 6 *Asterolasia phebalioides* – one of Victoria's Rare and Threatened plants growing in Melbourne Gardens

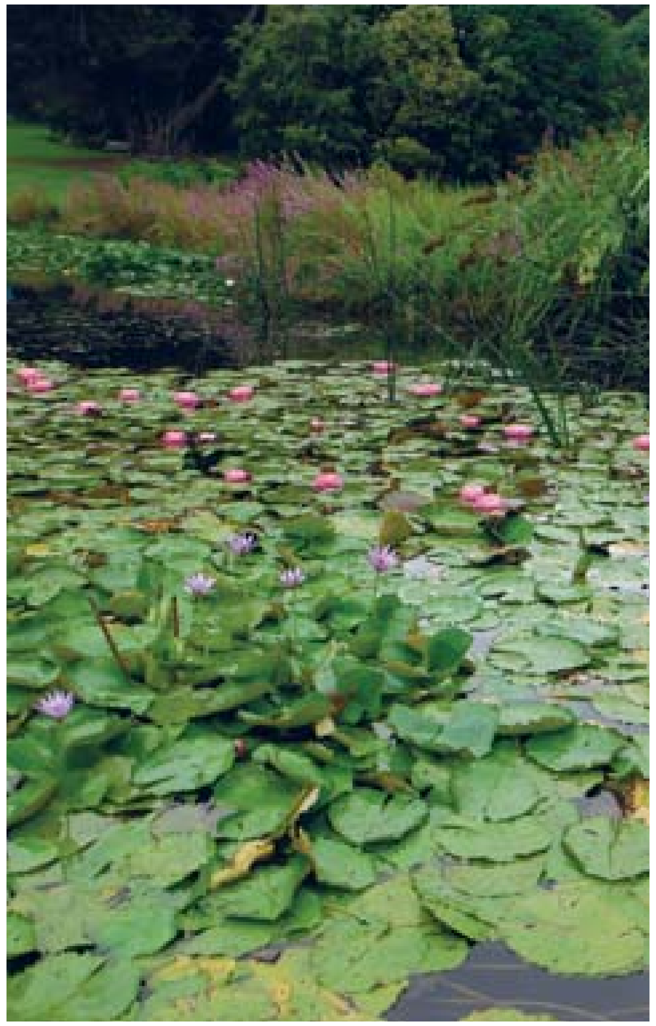
Maintaining reduction in air temperatures

Atmospheric cooling of between 2 °C and 8 °C is a major benefit provided by urban vegetation through the process of evapotranspiration.[11] In January 2013, a study commissioned by the Melbourne office of the Bureau of Meteorology (BOM) on data from 1998–2012 found significant temperature variations when the data from the Melbourne Regional Office (086071) station was compared with other BOM stations based in the outer suburbs. In particular, Melbourne Gardens' Automatic Weather Station (AWS) recorded average temperatures of about 1.7 °C less than Melbourne City.[12] Studies of microclimates in the Gardens using temperature loggers were undertaken from 2012 to 2015 (continuing) for 19 landscape areas across the site to date. Of 170 days greater than 30 °C, maximum temperatures were on average up to 4.3 °C cooler in the Gardens compared to what was recorded for Melbourne City. Some sites, such as Fern Gully and Oak Lawn were up to 6 °C cooler in maximum temperature during this reference period.

During the January 2009 heatwave in Victoria there was a marked increase in heatstroke and human mortality from prolonged higher than average temperatures.[13] Maximising the benefit of landscape spaces that provide shade and environmental cooling, such as in Melbourne Gardens, will become increasingly important for visitor relief and comfort. Effective landscape transition will ensure adequate canopy cover and provision of evapotranspirative cooling under future warmer climate conditions. Such cooling tends to be improved with higher levels of soil moisture, and may be reliant on sustainable irrigation water supplies.

Figure 7 Fern Gully – a prime location for visitors to escape the heat
Photo: Janusz Molinski

Figure 8 Wetland planting in Nymphaea Lily Lake



3.3 EDUCATION

Landscape succession can be used to highlight the effects of climate change within education programs. Demonstration gardens provide a very effective way of communicating 'take home' messages and ideas for the home gardener. The Water Conservation Garden and Guilfoyle's Volcano are fine examples that have been used to show landscape responses to a changing environment. Future climate-focussed projects will address the need for landscape transition within Melbourne Gardens with the added benefit of public education.

The successful management of landscape change is expected to require further development of expertise in subjects such as plant selection, climate modelling, plant physiology, and vegetation ecology and succession. A focus on landscape change is expected to become a driver for professional development that can in turn address other organisational needs.

There has been limited planning worldwide for managing living plant collections and landscapes under a climate change scenario. Skills gained through implementation of the Landscape Succession Strategy could provide Royal Botanic Gardens Victoria with a leadership opportunity in this field. Current and future partnerships with like-minded organisations, local government and researchers can communicate a powerful and far-reaching message about climate change and its links to human activity.

3.4 ECONOMIC

Reducing water, energy and infrastructure costs

Water use for irrigation results in a substantial cost that is becoming increasingly difficult to sustain. The current target is to significantly increase the proportion of alternative, more sustainable water sources compared to potable-sourced supply. However, alternative water sources often require additional energy for pumping and treatment that can be costly – Melbourne Gardens has installed an extensive photovoltaic cell system to partly mitigate these costs.

Significant energy savings can also be realised through shading of buildings in summer, either by trees, green walls or rooves, all reducing the need for air conditioning – a design factor to be considered in future developments. Extensive canopy cover can prolong the lifespan of infrastructure assets, such as asphalt, by shading them from harmful UV rays, potentially by 30%.[14] With more appropriate plant selection against warmer, drier conditions and a continuing focus on energy and water use efficiency, costs are expected to become more sustainable.

Increasing carbon sequestration

Urban environments have been found to be quite effective at storing carbon in the soil as well as vegetation.[15] A review of past soil-survey results in Melbourne Gardens has found potential storage of Soil Organic Carbon (SOC) at approximately 100 tonnes/Ha at depths of between 0–30 cm in the landscape soils alone, and this may reach well over 150 tonnes/Ha at 0–100 cm depths.[16] Compared to vegetation, over 70% of carbon is held within the soil and globally, soil sequesters more carbon than the total amount stored within the atmosphere and plants.[17]

Managed transition of the landscape is more likely to assist in minimising soil carbon losses by maintaining a healthy canopy cover. Sustainable irrigation application could even increase the amount of carbon storage in the landscape. However, the role of Royal Botanic Gardens Victoria in facilitating substantial increases in carbon sequestration is probably better directed towards involvement in off-site revegetation or rehabilitation initiatives. For example, our botanical and horticultural expertise could be applied to biodiversity revegetation and urban greening projects.

Increasing revenue

The further development of expertise in strategic landscape management within a changing environment may also provide direct revenue benefits through consultancy. Indirectly, a strong reputation in this area could garner additional philanthropic support.

Figure 9 Irrigation Performance Evaluation Course regularly hosted at Melbourne Gardens

Figure 10 Part of photovoltaic system on the roof of the National Herbarium

Figure 11 Four-metre deep soil moisture sensor probe on Oak Lawn[1*]

Figure 12 Soil core showing old root channel at 3.6 metres

3.5 SCIENCE

Landscape succession has important implications for science, as it will allow the Royal Botanic Gardens Victoria to question and alter the living collections composition. Botanic gardens have played an important role in scientific research as they provide provenance and documented living collections of plants for such purposes. Research falls across diverse areas from particular taxonomic groups that allow questions to be answered about plant morphology or even about plant tolerances.

One of the big questions in relation to climate change is the tolerance of individual species to environmental parameters. Natural distributions reflect the realised species niche and not the potential niche of individual taxa (see also Appendices 5 and 6). Current species modelling attempts are based on the climate envelopes that species occur in, and not on the climate envelopes that they can thrive in. Living collections in botanic gardens have plants grown outside their realised niche and therefore have the potential to provide information that will improve models of plant distribution. This is important in developing predictions of species that are most at risk of extinction and informing conservation programs.

Other aspects of the scientific role of living collections in botanic gardens and how landscape succession may impact the science are articulated elsewhere in this document (see 'Plant conservation and protection of distinctive plants' in section 3.2 and 'Increasing carbon sequestration' in section 3.4).

A changing climatic environment brings new challenges for applied sciences such as botanical horticulture. Improvements to management practices in botanic gardens are grounded in robust scientific endeavour and this is particularly applicable to matters such as biosecurity, landscape hydrology, microclimates, plant water use, plant selection, plant performance and water quality. These are areas of opportunity to further develop existing areas of research that in turn can inform the improved sustainability of the broader urban environment.

[1*] Soil moisture sensor probes are being used for research by RBGV, The University of Melbourne and Sentek Technologies to determine zone of deep water extraction by trees and whether stormwater can be 'banked' in winter when more available for later use by the trees.

4.1 PROJECTED CLIMATE

Within the *Climate Change in Australia publications*[18, 19], there are summaries of projected changes to various climatic parameters combined with the level of scientific confidence of the change, set as low, medium, high or very high.

Where relevant, Table 1 outlines these changes, the levels of confidence and the potential impacts on Melbourne Gardens, based on a high-emissions scenario for 2090.

Table 1 – Projected climate parameter changes and levels of confidence

Climate parameter change	Level of confidence	Potential impacts on Melbourne Gardens
Increases in mean, daily maximum and daily minimum temperatures; hotter and more frequent hot days	Very high confidence	• Changes to optimum temperature ranges for plant species to the extent of likely loss of diversity • Increased impacts on visitor health and comfort • Increased energy consumption for cooling • Loss of employee productivity from excessively hot days • Increased evapotranspiration and subsequent water use.
Increased evaporation rates with largest rate of increase in summer	High confidence	• Increases in evapotranspiration and subsequent irrigation water use • Increased draw-down in lake levels over summer.
Increased solar radiation and reduced relative humidity in winter and spring	High confidence	• Increases in evapotranspiration and irrigation water use • Increased proportion of irrigation water use in winter-spring.
Less rainfall in winter (up to 25% less) and spring (up to 43% less)[20]	High confidence	• Reduced availability and volumes of stormwater to offset potable-sourced water use for irrigation • Possible environmental flow restrictions on use of rainfall-dependent water supplies (or similar) • Increased salinity of lake storages.
Increased intensity of heavy rainfall*	High confidence	• Possible increases in opportunistic use of stormwater volumes • Reduced efficiency of wetland treatment – increased suspended solids and nutrient loadings • More flooding and blockages of infrastructure • Increased risk of soil erosion • Storm surges and subsequent risk of saltwater intrusion from Yarra River.
Higher sea levels and more frequent sea-level extremes	Very high confidence	• Increased storm surges and risk of saltwater intrusion into Melbourne Gardens freshwater lake system; possible loss of freshwater biodiversity.
Frequency and duration of extreme droughts	Medium confidence	• Increased salinity of lake storages • Increased risk of extended cyanobacterial blooms • Increased use of potable-sourced water. • Possible environmental flow restrictions on use of rainfall-dependent water supplies (or similar).
Small increases in mean wind speed	High confidence	• May increase magnitude of gusts and increase of limb failure in mature trees.

* Timing and amount of change is unable to be reliably projected

Rainfall and temperature

For the Melbourne Gardens' living landscape, the most significant climatic changes are expected to be associated with temperature and rainfall.

Projections for Melbourne show lower than average rainfall and increasing temperatures into the future (see Table 2).

Table 2 – Summary of temperature and rainfall changes for Melbourne

Group	Parameter	Baseline data period	Baseline data	2090 +/-	2090 Result
Temperature	Annual Mean (°C)	1986-2005	15.9	+3.1	19
	Mean Days >35 (°C)	1981-2010	11	+13	24
	Annual Mean Maximum (°C)	1986-2005	20.4	+3.3	23.7
Rainfall	Annual Mean (mm)	1986-2005	631	-9%	574
	Winter Mean (mm)	1986-2005	147	-10%	132
	Spring Mean (mm)	1986-2005	180	-19%	146

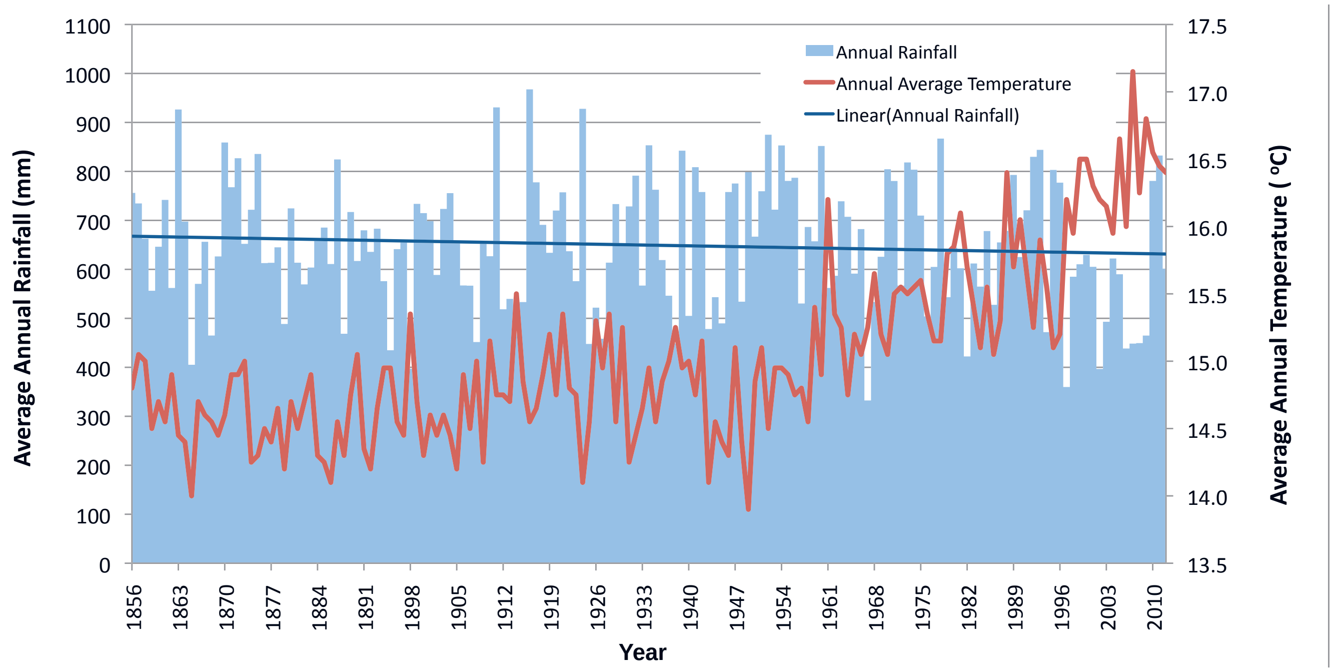
Assessments of climatic impacts upon Melbourne Gardens are based on data provided by Australian Bureau of Meteorology, and median values from a RCP8.5 (high emissions) scenario as indicated in projections from Grose M et al (2015) Southern Slopes Cluster Report, Climate Change in Australia Projections for Australia's Natural Resource Management Regions: Cluster Reports, eds. Ekström, M. et al., CSIRO and Bureau of Meteorology.

Most of the temperature rise in Australia has occurred since the 1950s, and this has been similar to the trends for data from the Melbourne Regional Office (086071) station (see Figure 13). It is also pertinent that projections for annual increases in the frequency of hot days by 2030 already have been somewhat realised.[21, 22] This observation is also comparable to measurements recorded by Melbourne Gardens' Automatic Weather Station. In terms of extreme heat, projections for increases in days over 40 °C are from 1.6 (1981–2010 baseline) to 6.8 by 2090 under a high emissions scenario.[23]

Melbourne's annual average temperature is 15.9 °C.[24] There are cool temperate taxa growing in Melbourne Gardens that are commonly found in other cities with mean annual temperatures ranging from about 10–13 °C.[25] It is plausible that since the 1950s, the shift in temperature bandwidth (see Figure 13) has already placed these species under significant physiological stress.

Figure 13 Melbourne Regional Office (086071) station – Trends in Average Annual Temperature and Rainfall shows trends of rainfall decline since 1856 and increasing temperatures since the 1950s (data sourced and adapted as provided from the Melbourne office of the Bureau of Meteorology)

Melbourne City - Trends in average annual rainfall and temperature



Further increases in annual average temperature by 1–3 °C are more likely to position these species even further outside their optimum growing conditions.[26] There are also increased risks to the health of other plants adapted to current annual temperature ranges if these temperatures increase over time.

Some studies have linked the combined effects of drought and higher temperatures as key factors to increased tree mortality within natural forests across the world. The implications of these effects are hydraulic failure from unsustainable evaporative water losses, and carbohydrate starvation from reduced photosynthesis (stomata closure on hot days) and increased respiration rates.[27, 28] Urban forests face similar threats from the same types of risks, and these are exacerbated by effects from the Urban Heat Island and growing urbanisation that may increase average temperatures even higher than projected.[29]

Current projections indicate that as the average temperature range shifts into a warmer state, there is an increased frequency of extremely high temperatures.[30] This risk is one of the most difficult to manage and should be considered in adaptive planning, especially for high value collections and landscape areas.

Melbourne Gardens was subjected to unprecedented temperature extremes with three consecutive days above 40 °C in January 2009 and four consecutive days in January 2014 (see Appendix 3). A record 46.7 °C was recorded on 7 February 2009.

These extremely hot conditions, combined with very low relative humidity levels, resulted in scorching and damage to a number of taxa across the Gardens, including some species previously presumed to be resilient.

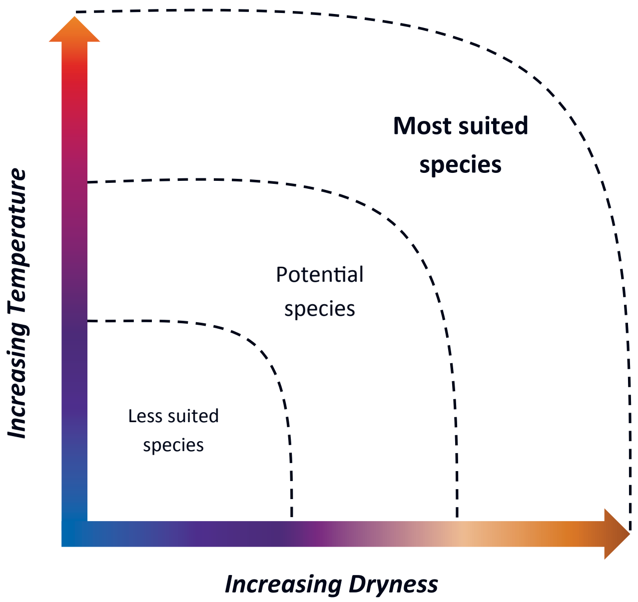
The higher probability of more frequent, extremely hot events could also be applied to rainfall deficiencies. For instance, a decline in average autumn rainfall for Southern Australia is considered to be at least partly a climate change signal.[31] If this was also combined with an atmospheric-oceanic phenomenon such as an El Niño episode, then the annual rainfall deficiency could be significantly more severe than previously experienced.

Climatic characteristics of heat-damaged taxa can also be used to identify other plants from associated natural environments that may be at similar risk. Assessment of a selection of these damaged species in Melbourne Gardens found that they would only typically experience about 53% of the rate of annual Vapour Pressure Deficit (VPD) (or evaporative demand) than what could occur in their natural environments. The risk of increasing VPD as a driver for plant mortality under climate change has also been described in scientific literature with xylem cavitation and carbohydrate starvation as factors in plant decline.[32]

Future plant selection will need to consider taxa that are more suited to an environment of increasing dryness and temperature (as shown in Figure 15), or that can be accommodated in (limited) microclimates providing protection from water loss and heat.

Figure 14 Scorching of *Meryta sinclairii* following 2009 heatwave

Figure 15 Plant selection under landscape succession



Stormwater

Rainfall patterns are projected to change by 2090 with average reductions of 19% to 18% for winter and spring respectively.[33] This can impact on the volume of stormwater harvested for irrigation purposes. Depending on the rate and amount of rainfall, and proportion of impermeable surfaces, there can be an amplification relationship between rainfall reductions and losses in run-off. In normal vegetated catchments, this relationship can be in the order of approximately 1:3.[34, 35] For example, the projected 19% average reduction in winter rainfall may result in a 57% reduction in run-off. For Melbourne Gardens, reductions in run-off are not expected to be as severe due to the high level of imperviousness of urban external catchments.

Melbourne Gardens' expected annual stormwater yield for landscape irrigation from the Working Wetlands project is an average of 55 ML, or up to 40% of annual requirement.[36] The effective application of this volume of water to maximise potable water substitution for landscape irrigation also relies to some extent on the basis of current research into innovative techniques to 'bank' winter-spring stormwater run-off in subsoils.[37]

The climatic projections for 2090 indicate an increase in heavy rainfall intensity.[38] This may result in some increase in opportunistic stormwater capture for irrigation. However, wetland treatment systems have a design bias to proportionally manage lower flows more effectively. An increase in high-flow frequencies could result in additional untreated nutrients and pollutants entering the lake system, and a potential overall reduction in harvestable volume due to high flows bypassing interception pits and pipes.

Sea level rise

Global sea level is projected to rise 45–82 cm by 2090, relative to 1986 to 2005 levels.[39] As a consequence, the risk of saltwater intrusion into the freshwater Ornamental Lake may be increased. The combination of storm surges and higher tidal levels within the Yarra River will reduce the outlet flow during flood events, increasing the risk of localised flooding of Melbourne Gardens' assets. The Ornamental Lake is ecologically important as it represents the closest remnant freshwater system to the CBD; the natural lagoon pre-existed the Melbourne Gardens. There already has been a precedent of intrusions of the Yarra River into the Ornamental Lake through the lake outlet during high tide events, as the drainage pipe is essentially located at sea level. Future sea level rises combined with storm surge situations could increase the likelihood and frequency of intrusion occurrence. There may also be the risk of saltwater permeating through the land between the Yarra River and the Ornamental Lake as there are substantial filled sections dating from when the river course was altered in the late 1800s. An increase in the salinity of the lake water presents issues with its suitability for landscape irrigation.

Figure 16 Very high water level in the Yarra River on 9 December 2012, when brackish water flowed back through the outlet into the Ornamental Lake

4.2 WATER SUPPLY AND MANAGEMENT

Future water demands and costs

From 1994–95 to the present, Melbourne Gardens has developed landscape water use efficiency to enable an average reduction in potable-sourced water use by about 50%.[40] This was during a time when water scarcity dominated concerns, mainly due to the persistence of dry conditions during the unprecedented 1997–2009 'Millennium Drought' that affected much of southeast Australia.[41]

Apart from a decline in water availability due to climatic shift, water security remains an issue due to increasing water and electricity costs (distribution, pumping and treatment), and further demands on the overall water resource by a growing urban population.

Estimates of future water demand indicate a 22% increase. This is based on annual averages of 9% less rain and a 12.5% rise in evapotranspiration by 2090.[42, 43] Average annual water use for landscape irrigation could then rise from 130 ML to 159 ML and may even exceed this during extreme droughts, further strengthening the need to transition from the current suite of plant species with their associated irrigation demand.

Water costs have risen from $880/ML in 1998–99 to $3,041/ML in 2014–15 (see Table 3). Future cost increases for water are expected to be based on annual CPI rates. Current offsets in potable water use from stormwater supply are also at risk from climatic reductions in rainfall and increased evaporation, which drives the need to source other non-rainfall-dependent water supplies.

Table 3 – Water use and costs

Water use Category/Period	Volume (ML)	Equivalent cost from 2015 –16
Annual Average Water Use *(2000–2010)	130	$405,210
Annual Average Water Use *(2000–2010) +22% climate change demand to 2090	159	$495,603

* This excludes the very wet and record-breaking La Niña years during 2010–2012.[44]

One of the water management performance targets includes setting an upper boundary of 900 mm combined annual precipitation from irrigation and rainfall. For instance, if annual rainfall were only 400 mm, then it is currently accepted that 500 mm of supplementary irrigation may be applied across the irrigated landscape. However, many trees in Melbourne Gardens appear to originate from higher annual rainfall regimes or have higher requirements than what is typically experienced in Melbourne, especially during the recent decade (see Figure 17).[45, 46] Some of these species may originate from drier soil and microclimates within these rainfall regimes, but it was observed that the health of some of these trees declined during the Millennium Drought (1997–2009) even with provision of supplementary precipitation through irrigation.

Increased irrigation needs from visitation

Growing visitation and revenue generation through outdoor events is already driving increased irrigation needs to improve the wear and tear resilience of turf areas. Additional irrigation may also be required in the future as a means to provide environmental cooling through landscape evapotranspiration for visitor health.[47]

In 2013–14, there were 1.54 million recorded visits to the Melbourne Gardens.[48] Applying Victoria's current population growth of 2.0% per annum combined with a trend analysis of past visitation, the Gardens may realise between 2.3 and 2.5 million visitors per annum by 2036, and between 4.6 and 7.0 million visitors per annum by 2090.[49] From 2005–06 to 2014–15, visitor numbers to Melbourne Gardens have grown by 24.2% or about 3% per financial year — exceeding population growth rates — although there are peaks and troughs depending largely on weather conditions. Further, there may be significant increases in international visitation from tourism as economic conditions improve in other countries.[50] Regardless of these estimates, an increase in drier and warmer conditions seems likely to attract greater numbers of visitors to green spaces, and over a longer extent of time, which is a significant resourcing challenge.

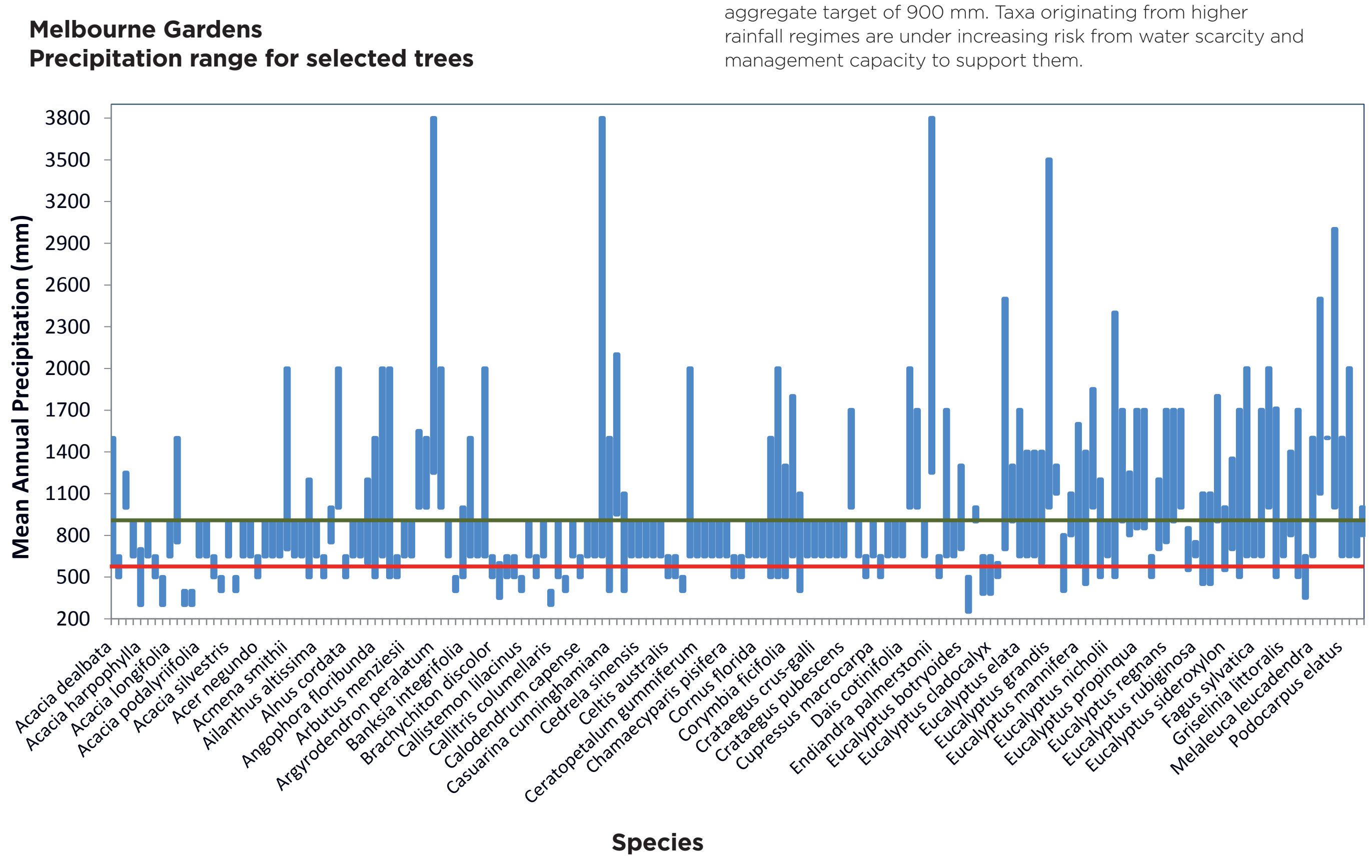


Figure 17 Minimum rainfall requirements for a range of trees growing in Melbourne Gardens[45, 46]. The red line shows the projected annual average rainfall of 574 mm for 2090 and a large number of taxa with higher rainfall requirements. The green line shows the current combined precipitation (irrigation and rainfall) aggregate target of 900 mm. Taxa originating from higher rainfall regimes are under increasing risk from water scarcity and management capacity to support them.

Azolla and Cyanobacterial blooms

Relatively static water bodies with high levels of nutrients such as the Ornamental Lake can favour growth of problematic algae, plants and cyanobacteria.

Blooms of potentially toxigenic cyanobacteria (blue-green algae) have been a regular occurrence over the warmer months in the Ornamental Lake since the 1980s. Cyanobacteria have a range of physiological traits that may favour them under future climatic conditions, especially when combined with changes to lake hydrology.[51] For example, the optimal range of water temperatures for promotion of cyanobacterial growth rates is considered to be >20–25 °C.[52] The projections of temperature increase to 2090 could result in cyanobacterial blooms within the Ornamental Lake dominating earlier, during November, and reaching unprecedented levels in February (projected average 25 °C). Additional wetland treatment, increased water recirculation and additional planting may help reduce this risk, but the certainty of success is unknown.[53] An increase in toxic cyanobacterial blooms not only has impacts on aquatic biodiversity, landscape amenity and potential risks to human health, but also on effective lake water treatment and supply for landscape irrigation.

Azolla rubra is a floating water fern that demonstrated prolific growth in the Melbourne Gardens' lake system from March 2012 to July 2012 and from March 2015 to May 2015. If uncontrolled, it can quickly cover the surface of entire water bodies and presents significant management issues such as visitor safety (children walk onto *Azolla* thinking it is a lawn surface), and damage to lake ecology by shading and deoxygenation of water. Removal of *Azolla* is highly costly, whether by machine or by manual labour. While *Azolla* is favoured by high nutrient levels, these had been reduced by over 70% by 2014–15. It is postulated that the addition of more wetlands, whilst reducing nutrients, may also have increased the areas of stable water required for *Azolla* to thrive. *Azolla* is also benefited by warmer water temperatures, with 25 °C being considered optimal for a similar species — *Azolla filicuoides*.[54] Future warming of the lake system may increase the risk of *Azolla* blooms for extended periods of the year.

Figure 18 Cyanobacteria bloom (2006) in Long Island Backwater

Figure 19 *Azolla rubra* bloom on Ornamental Lake, 2012

4.3 LANDSCAPE SUCCESSION IN A MATURE LANDSCAPE

Identifying matching climates and plants at risk

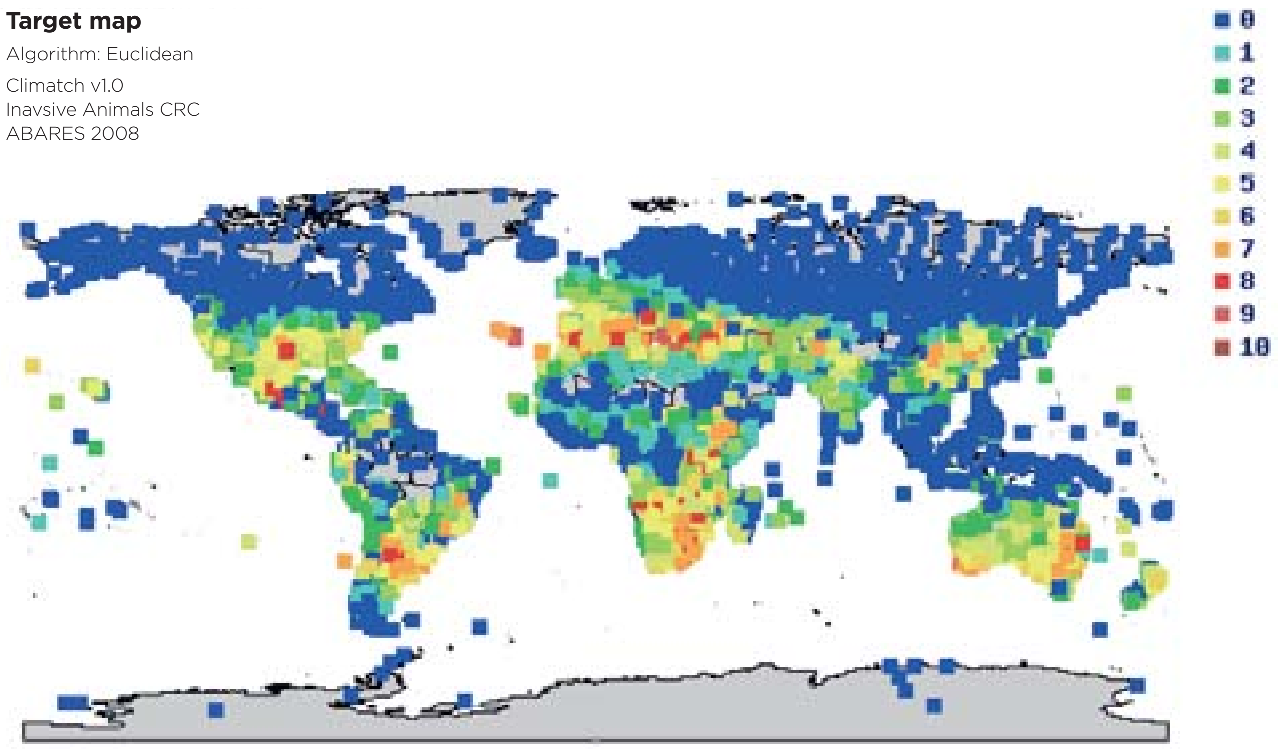
Based on annual average temperatures projected for 2090, Melbourne is expected to be warmer than present-day Sydney, and may resemble the current temperatures of locations such as Algiers-Algeria, Buenos Aires-Argentina, Casablanca-Morocco, Perth-Australia, San Diego-USA, Sydney-Australia and Tijuana-Mexico (see Appendix 4). More locally, the Climate Change in Australia website offers a Climate Analogues tool, which can be used to compare matching towns in Australia to Melbourne under a given climate future scenario. Under a high emissions scenario of maximum consensus, with average annual rainfall reductions of 9% and annual average temperature increases of 3 °C, the following towns are listed as being analogous to Melbourne: Cootamundra, Corowa, Cowra, Esperance, Forbes, Gawler, Keith, Parkes, Wagga Wagga, Wangaratta, West Wyalong.[55] These towns could be used to examine the range of plant taxa currently being grown to inform future plant selection choices.

Locations with close-matching climate classification to that projected for Melbourne in 2090 may not exist (see Appendix 4). Many locations that share similar climate classifications mostly do not experience the same seasonality, high temperature extremes, drought conditions and evaporative demand. Tools such as climate matching software still only provide a simplification of optimum growing conditions.

Establishing a given plant's environmental preferences is not a straightforward task considering the complex combination of characters and, importantly, the lack of knowledge of phenotypic expression under different environmental conditions for individual taxa. To improve accuracy, multiple sources of data, including both anecdotal observation and scientific studies, are recommended. However, these assessments are very time-intensive — simple, climatic evaluations for one taxon could take up to several hours. The Living Collections Database (LCD) could be used as a powerful tool for mapping plant climatic distributions. Many individual taxa are given geographical origins within the LCD using a system defined as a Basic Recording Unit and can be matched with Köppen-Geiger Climate zones (see also Appendix 5).[56]

Conservative assumptions and estimates of a specific plant's tolerances should be adopted as a precautionary approach to adapting to climate change.[57]

Figure 20 Climate match map for possible plant selection regions of the future. This map as generated is based on average annual temperature (17.8 °C) and rainfall (598 mm) for Algiers, Algeria, which has similar parameters to those projected for Melbourne in 2090. Highest scores show closest match to the parameters. Used with permission from ABARES (2008) Climatch. http://adl.brs.gov.au:8080/Climatch/climatch.jsp (retrieved May 2013)[58]



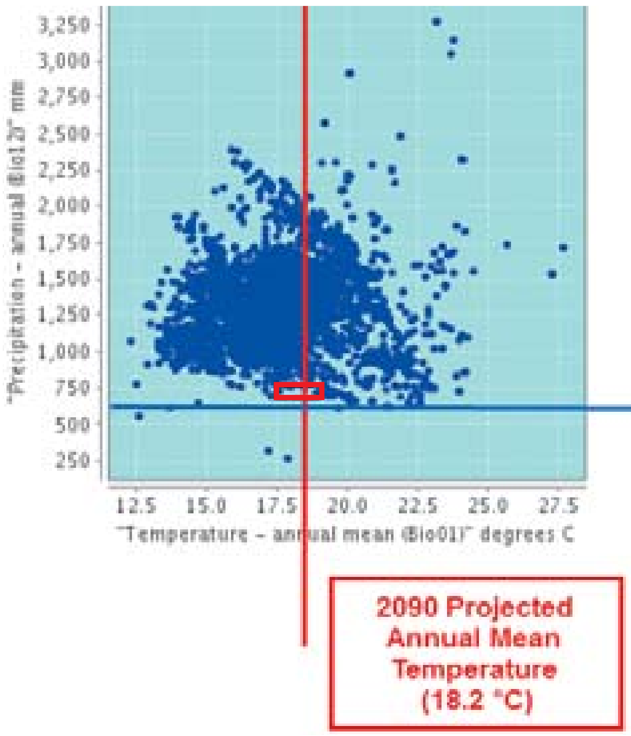
For Australian taxa, there is greater access to quality data in assessing climate change risks to specific species. The Atlas of Living Australia contains information on all known Australian fauna and flora species sourced from field observations, collected specimens and surveys.[58] Particularly, herbaria contribute valuable, verified data on flora. The Atlas of Living Australia not only provides known distribution data, but tools to analyse relationships such as climatic parameters; for example, *Lophostemon confertus* (Brush Box) is a tree species that was observed to perform poorly during the Millennium Drought. Within the spatial portal, various graphical analyses can be generated along with distribution maps to highlight species that may be at risk, or resilient, or as having potential for provenance-based replacements.

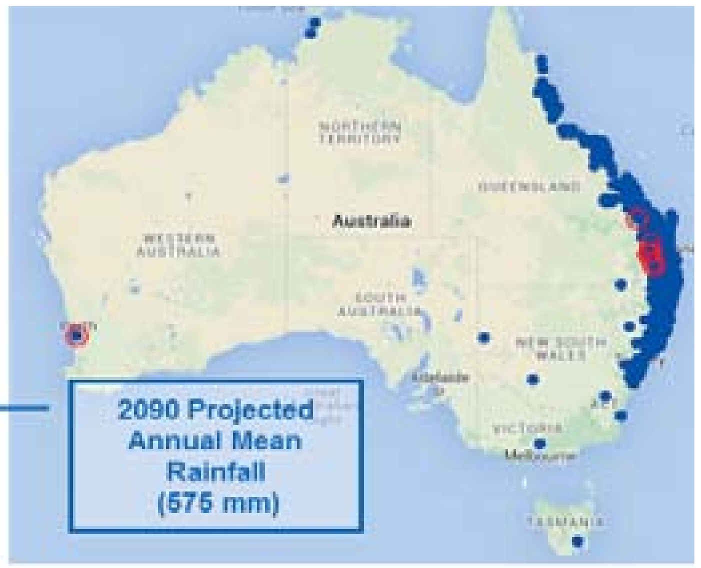
Restrictions on obtaining diverse plant material
While identifying new taxa appropriate for anticipated future climates is one challenge, actually obtaining alternative plants is another, particularly if international accessions are involved. It will be important to increase the diversity of new taxa known to suit predicted climates and to select more suitable phenotypes of taxa already represented in the collection. Quarantine requirements and biodiversity protocols (Nagoya Protocol, Convention on Biological Diversity[59]) present limitations to sourcing plants from elsewhere. Building of relationships and partnerships with kindred organisations will be vital in reducing these difficulties.

Figure 21 Scatter plot graph and distribution map generated from Atlas of Living Australia for *Lophostemon confertus* Brush Box

These images show distribution of *Lophostemon confertus* and an analysis of relationships with annual mean rainfall and annual mean temperature. The scatter plot graph on the left suggests that most distributions fall into a rainfall range of about 900—1600 mm; and a temperature band of about 13—19 °C.

Many of these specimens may be able to tolerate a wide temperature range, but the lower limit of rainfall appears to be quite marginal. The red square in the scatter plot graph and red circles in the map display a selection of specimens that may be more suited to Melbourne's conditions in the future.





Community perceptions of the current landscape
Many visitors may have preconceived notions of how the heritage landscape of Melbourne Gardens should appear based on their experience in recent times. An understandable inclination would be to view the relative lushness of the landscape as what William Guilfoyle actually designed. In fact, the relative scarcity and unreliability of water supply at the time would have made it very difficult to support the landscape enjoyed today.[60] Early photographs show a more open landscape with a greater prevalence of plantings better suited to arid conditions.

It appears likely that the 'look and feel' of the landscape has changed considerably since Guilfoyle's period due to the availability of water supply and the maturity of plantings. There is also evidence to suggest there were periods of annual rainfall (especially during the late 1940s to 1990s) that accumulated above-average volumes of water in the soil profile and as a result may have supported more lush plantings (see Appendix 7). Renewing a focus on flora more suited to the current and future climate of Melbourne would probably be more in line with Guilfoyle's original design.

The task ahead is to maintain the heritage garden character and to support visitor wellbeing, but with a partially different palette of climate-suited vegetation. Effective public communication will be essential to describe the importance of succession and highlight the organisation's commitment to maintaining the landscape style.

Incorporating new taxa within established plantings
The maturation of the Melbourne Gardens landscape in many areas limits effective establishment of new vegetation. There are high levels of root competition for nutrients and water, significant shading from overhead canopy, and water-repellent soils in some areas. It is questionable how effective the establishment of young plants will be within these unfavourable conditions without reduction or removal of dominant tiers of vegetation.

In the same manner, effective landscape change will require careful, strategic removal of competing vegetation and replanting to provide managed plant succession, or the 'ecological space' required for diverse replacement landscapes to develop. This method already has been successfully implemented for sites such as Guilfoyle's Volcano, Long Island, the Perennial Border, the Species Rose Collection and the Water Conservation Garden. In areas where there has been inadequate clearing of dominant vegetation, such as the California Garden, establishment of healthy, new plantings has been problematic.

Figure 22 Circa 1890s Arid planting near Terrace Tearooms

Figure 23 Dominance of mature trees in the Australian Forest Walk shows how tiers of vegetation can compete with new plantings (foreground) for nutrients and water

Aging tree population

Diameter at Breast Height (DBH) of trees is a standard measurement in arboriculture practice. It can also be applied as a predictor for estimating tree age. It has been suggested that within an urban forest no more than 40% of the trees should be under 20 cm DBH (juvenile), 30% from 20–40 cm DBH (semi-mature), 20% from 40–60 cm DBH (mature), and 10% in the >60 cm DBH class (over-mature).[61]

Many specimen trees in Melbourne Gardens are nearing the end of their Useful Life Expectancy (ULE), with 13.6% of 1,195 trees surveyed with DBH ≥ 30 cm estimated to require replacement in 10 years and 25.2% of trees in 20 years.[62] Indeed, arboricultural staff are facing current challenges in actively managing risks associated with mature tree populations, including reactive removals and unplanned opening up of tree canopy.

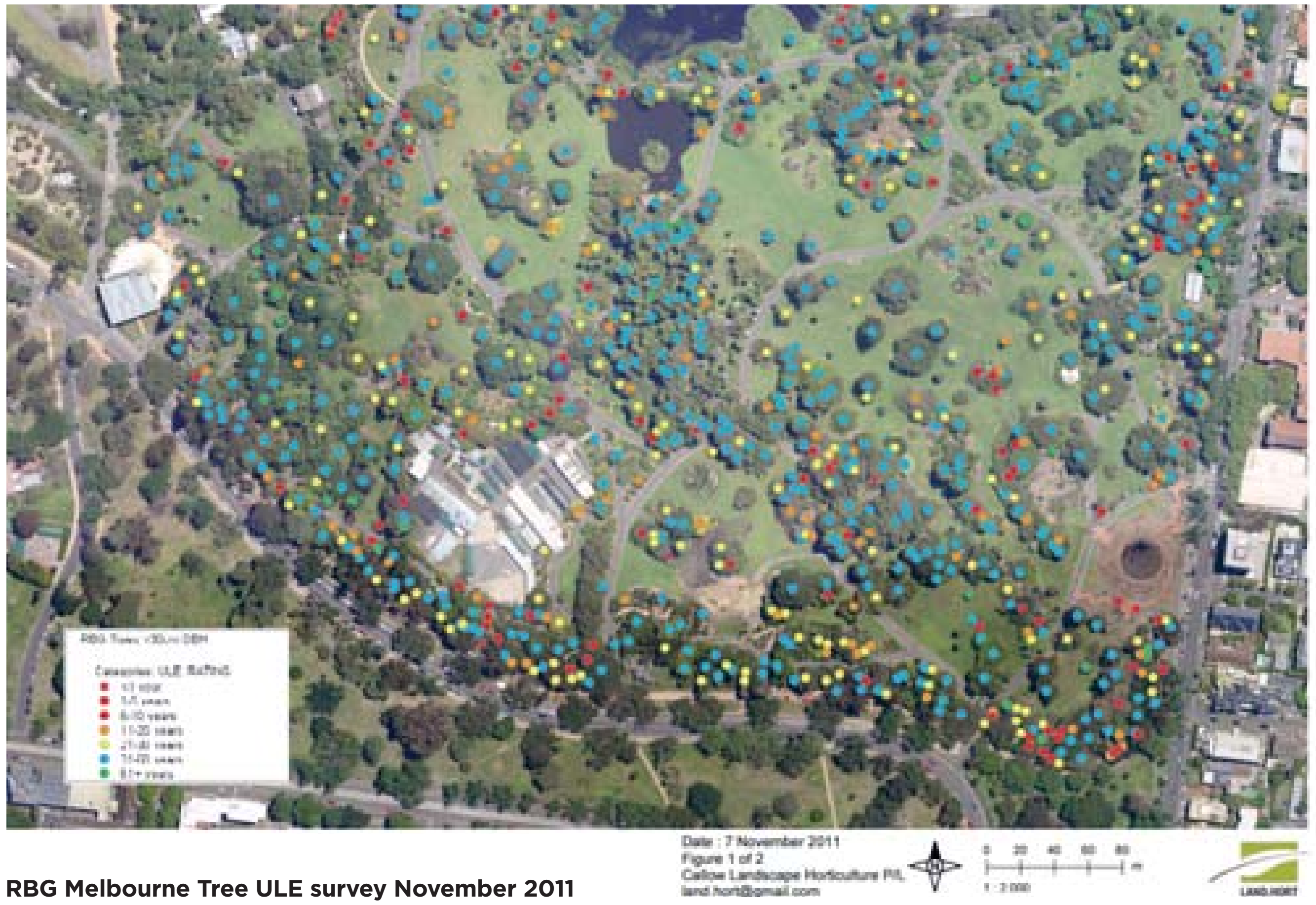
Within the ULE assessment, about 87% of the trees were assessed as being either mature or over-mature. In effect, this reflects what has been described previously as a layer of climax vegetation. Effective establishment of replacement specimens may be impaired by existing tree dominance, primarily through shading and root competition.[63]

Further refinement is required to the existing approach of strategic removal and replacement of those trees identified at highest risk of senescence. Trees deemed to be at high risk of susceptibility to climate change should also be reviewed in context with ULE assessments. Particular challenges are presented by sustaining the health of mature specimens that are classified either under commemorative or significant tree registries, but are approaching the end of their useful life and/or are future climate sensitive.

The practice of using lawn areas for replacement tree planting to reduce competition is limited by constraints such as the need to maintain historically important landscape vistas and void space.

It is also paramount to develop a shared community understanding for the necessity of careful tree removal as an important part of landscape rejuvenation. Effectively communicating the need for this work is arguably a greater challenge than actually undertaking it.

Figure 24 Section of Useful Life Expectancy (ULE) tree survey of Melbourne Gardens – a significant number of trees were assessed with a ULE of less than 10 years and many more with a ULE expiring before the projected conditions of 2090



4.4 BIOSECURITY

Invasive plant species and other pests more biologically adapted to the new regimes also add threats to the living collections. Some pests preferring cooler climates may become less of a problem, but the risk of a warmer climate could preferentially favour others.[64, 65] For example, the Palm Pink Rot *(Gliocladium vermoesenii)*, usually seen as a tropical disease, has killed Bangalow Palms *(Archontophoenix cunninghamiana)* in the landscape since 2004. The earlier emergence and increased generations of Elm Leaf Beetle and African Black Beetle, which prefer the projected drier winters, may increase their impact. An existing threat such as Myrtle Rust may expand its infectious season and pathogenicity.

Unfortunately, some plant species more suitable for the future climate also present a higher risk of becoming invasive. Weed risk assessments will have to include projections of future climate suitability and not just be considered for existing conditions.

4.5 INFRASTRUCTURE

Management of constructed assets is a continuing challenge, with aging drainage systems and path networks. The design and condition of many of these assets are anticipated to be even less suited to a changing climate with its increasing risk of extreme weather events, including high intensity rainfall and heatwaves.[66]

Even with existing rainfall, efficient disposal of stormwater is already restricted with regular overland flow and pooling of water in some areas. These issues in turn increase the risk of landscape soil erosion, waterlogging and subsequent pest problems, such as root-rotting organisms.

Infrastructure assets such as the Automatic Irrigation System, constructed in 1993–94, now have major essential components (such as the pipe network) that are nearing the end of their useful life. In existing risk management plans, the timely distribution of water across the landscape is considered of utmost importance for the health of living collections. These risks are exacerbated by asset failure during a more demanding climate.

Outdoor spaces protected from weather extremes, such as high levels of solar radiation, are important for people's wellbeing during a warming climate. Tree shade has been found to substantially reduce physiological equivalent temperatures of paved areas. The hotter the area becomes, the greater moderation of temperature the trees proportionally provide.[67, 68] Locations like the Jardin Tan cafe at Observatory Plaza and The Terrace tearooms beside the Ornamental Lake are shade-limited when considering visitor thermal comfort on hot days. Improving the design of these spaces will require new or modified infrastructure and services to support landscape changes in order to provide relief, preferably using plants.

Figure 25 Pacific Dunlop Observatory Plaza is considered to be poorly suited for future climate extremes, with insufficient cooling shade

5 Strategies and Targets

To achieve our Landscape Succession Strategy's goal of providing future visitors with a place of beauty, biodiversity and refreshing green space in a changing climatic environment, we have developed five Strategies and Targets. These will be reviewed on a periodic basis with regard to the latest climate science and organisational direction.

Strategy 1: Actively manage and transition the Melbourne Gardens landscape and plant collections
Target: By 2036, 75% of taxa in the Gardens are suitable for the projected climate of 2090[2*].

Actions: [3*]

- By 2017–18, achieve at least 90% accuracy of matching living specimens with the Living Collections Database.
- Develop specific actions for transition of plant collections and threatened species deemed to be at highest risk from climate change, including networking and effective plant exchange with other botanic gardens and similar organisations[4*].
- Facilitate improvements to the conservation of Victorian rare and threatened flora through the network of Victorian regional botanic gardens.
- Improve approaches to assessing suitability of existing and new taxa against the expected climate of 2090, including development of specific collections with expected future climate-resilient flora, building employee expertise, educating our visitors, and planting to maximise microclimates.
- By 2017–18, construct a module within the Living Collections Database to monitor and document taxa showing either tolerances or intolerances to heat stress and/or water scarcity.

Strategy 2: Establish a mixed-age selection of plants composed of a high diversity of taxa
Target: By 2036, plant diversity is equal to or greater than 8,400 distinct taxa of mixed age with greater than 35% wild provenance-sourced plants[5*].

Actions:

- By 2036, 20% of woody and arborescent vegetation is juvenile, 50% semi-mature and 30% mature.
- Conduct audit and mapping of all trees including Useful Life Expectancy (ULE) methodology and climatic considerations.
- Produce landscape planning and mapping overlays showing collection and landscape development priorities, ULE tree canopy and climate susceptibilities.
- Complete and implement a tree and vegetation renewal schedule based on a matrix approach according to priorities of highest risk, lowest ULE rating, and opportunities to maintain and improve plant diversity and heritage qualities of the Gardens.
- Adapt Royal Botanic Gardens Victoria Strategic Tree Plan and management to the evolving nature of the tree population.

Strategy 3: Maximise sustainable water use and supply security
Target: By 2020, 100% of landscape irrigation needs are provided by sustainable water supplies.

Actions:

- By 2020, secure additional environmentally sustainable water supplies to support 100% of landscape irrigation needs against predicted climatic demands of 2090.
- Review effectiveness of existing irrigation systems against projected water consumption and site requirements, and rectify deficiencies.
- Establish and develop research programs that support best practice irrigation, optimal use of stormwater, and effective management of water storage under a changing climate to reduce reliance on potable water.
- Actively manage and reduce silt levels in the Ornamental Lake to maximise the potential draw-down of water levels for irrigation use.
- Increase the number of taxa and areas requiring less supplementary irrigation while maintaining the overall heritage landscape style, and using microclimates (including waterside locations, protected areas and glasshouses) to grow plants with more specialised requirements.

[2*] This target does not preclude the growing of plants in microclimates (e.g. near water bodies or in glass and shade houses) that would allow them to tolerate otherwise more extreme conditions.

[3*] Where timelines are not provided, actions are anticipated to be completed by 2036.

[4*] Such actions may include seeking more appropriate phenotypes of taxa already represented in the collection.

[5*] This maintains the current plant diversity and increases (from 20%) the proportion of wild provenance-sourced plants.

Strategy 4: Maximise the benefits of the green space and built environment through landscape design
Target: Improve green and built infrastructure capable of withstanding predicted climatic extremes.

Actions:

- By 2017–18, conduct audit of existing landscape spaces for suitability against future climatic conditions and use trends.
- By 2020 identify, enhance and develop landscape spaces specifically to improve visitor experience and wellbeing, especially in high patronage areas.
- Complete an audit and hydrological survey to identify paths and drainage systems at highest risk from climatic extremes.
- Improve stormwater disposal by landscape modification (where appropriate) and construction of infrastructure.
- Prioritise systems at risk within Asset Management systems and implement improvements.

Figure 26 *Nuxia floribunda*, a cream-flowered riparian tree from Southern and Tropical Africa, is expected to be suitable for future temperatures when grown near water

Strategy 5: Improve understanding of the impacts of climate change on botanical landscapes
Target: Effectively communicate with the botanical and public communities on the interactions between climate change, biodiversity, green spaces and plant benefits.

Actions:

- By 2017–18, develop a communications strategy that integrates education, professional development and public understanding.
- Prepare and implement specific educational programs to raise public consciousness of climate change impacts and related RBGV initiatives.
- Foster the development of employee expertise to support implementation of the Landscape Succession Strategy.
- Lead and facilitate networks and partnerships with relevant organisations in landscape-related conservation of biodiversity, human health, urban greening and water management.
- In partnership with the Australian Research Centre for Urban Ecology (ARCUE) and/or relevant universities, establish baseline fauna biodiversity and monitor indigenous flora and fauna biodiversity to maintain species richness where possible.

6 Appendices

APPENDIX 1 – GLOSSARY

Term	Definition
Biodiversity	The variety of all life forms on Earth; the different plants, animals and micro-organisms; their genes; and the terrestrial, marine and freshwater ecosystems of which they are a part.
Climate Change Adaptation	Activities undertaken to manage the effects from both actual and projected changes in climate.
Climate Change Mitigation	The effect of activities undertaken to directly prevent or reduce the influence of human-caused (anthropogenic) changes in climate.
Climate Normals	Statistics calculated over a standard period (commonly a 30-year interval) that are generally used as reference values for comparative purposes. In Australia, the current reference climate normal is generated over the 30-year period 1 January 1961 to 31 December 1990 (http://www.bom.gov.au/climate/cdo/about/about-stats.shtml).
Cultivated landscape	A landscape with meaning to humans for scientific study, quality of life, traditional practices or recreation in urban environments.
Evapotranspiration	Evaporative loss of water from soil and plants.
Landscape succession	Shift in vegetation composition and structure in response to human needs and preferences and changes in the biophysical environment.
Macroclimate	General large-scale climate of a large area or country, as distinguished from the mesoclimate and microclimate.
Melbourne Gardens	Refers to Royal Botanic Gardens Victoria's garden site in Melbourne 3004.
Mesoclimate	Climate of a relatively smaller area because of differences in altitude and exposure, it is not representative of the larger macroclimate. For example, the climate of Melbourne City may be considered as an urban mesoclimate compared to the Port Philip catchment, or even the State of Victoria.
Microclimate	Distinctive climate of a relatively small scale area compared to the background mesoclimate. It could be a garden bed, garden, public landscape or part of a city. Temperature, rainfall, wind or humidity will usually be subtly different to the conditions prevailing over the entire area. For example, the Fern Gully could be construed as having a unique microclimate compared to the mesoclimate of Melbourne Gardens.
Montane	Relatively high altitude plant habitat (i.e. mountainous); usually cooler and wetter than lowland environments.
Natural landscape	Comprised of original vegetation that has not been significantly altered by humans. In the context of this report, we are primarily using the term to describe pre-colonial vegetation.
Precautionary principle	Where there are risks of serious or irreversible environmental damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation.
Representative Concentration Pathways (RCPs)	Range of emission scenarios used by the Intergovernmental Panel on Climate Change (IPCC). RCP8.5 represents a high radiative forcing from a high-emission scenario.
Riparian	Adjacent to water courses and water bodies.
Royal Botanic Gardens Victoria	Refers to the whole organisation, including the sites at Melbourne and Cranbourne, the National Herbarium of Victoria, the State Botanical Collection and the Australian Research Centre for Urban Ecology (ARCUE).
Vapour Pressure Deficit (VPD)	VPD is calculated by comparing the actual amount of water vapour in the air to what it can hold (saturation). It measures the capacity for plant water loss. A high VPD usually occurs with high temperatures and low relative humidity, and typically equates to high evapotranspiration potential.

APPENDIX 2 – BASIS FOR CLIMATE PROJECTIONS

Analysis of the future climate has mostly been sourced from the latest reports produced by CSIRO and the Bureau of Meteorology published on the Climate Change in Australia website. These latest analyses follow the release of the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report published in 2013. Australia has a number of Natural Resource Management (NRM) regions.

Specific climate change projections for Melbourne are classified within the Southern Slopes NRM cluster. Due to the long lead times required to effectively modify and establish new landscapes, a circumspect approach has been applied in this Landscape Succession Strategy with an emphasis placed on high radiative forcing from a high emissions scenario (RCP8.5) and subsequent projections for the 2080–2090 time period.

APPENDIX 3 – MELBOURNE GARDENS: CONSECUTIVE DAYS GREATER THAN 40 DEGREES CELSIUS FROM 1999 TO 2014

Date	Maximum Temperature (°C)	Minimum Relative Humidity (%)	Maximum Vapour Pressure Deficit (VPD) (hPa) ‡a
30 December 2005	40.6	10.4	68.0
31 December 2005	44.8	8.2	86.7
21 January 2006	42.0	21.0	64.4
22 January 2006	43.5	14.9	75.1
28 January 2009	45.2	8.3	88.2
29 January 2009	45.6	10.5	88.1
30 January 2009	45.6	9.1	89.5
7 February 2009	**46.7**	**8.0**	**95.6**
14 January 2014	43.9	12.8	78.6
15 January 2014	42.7	13.8	73.0
16 January 2014	44.9	11.3	84.2
17 January 2014	45.6	9.1	89.4
8 February 2014	41.6	12.2	70.0
9 February 2014	40.9	10.6	68.9

Based on Bureau of Meteorology climate normals (1961—1990), Melbourne's summer VPD average is calculated to be about 11 hectopascals (hPa). Many of the susceptible taxa studied to date only experience a typical VPD summer average of 6 hPa in their natural habitat.

APPENDIX 4 – COMPARISON OF MELBOURNE CITY AVERAGE TEMPERATURES WITH SELECTED LOCATIONS AROUND THE WORLD[6*]

Location	Climate Period	M1 (Win)	M2 (Win)	M3 (Spr)	M4 (Spr)	M5 (Spr)	M6 (Sum)	M7 (Sum)	M8 (Sum)	M9 (Aut)	M10 (Aut)	M11 (Aut)	M12 (Win)	Annual Average
Toliara, Madagascar	1971-2000	20.6	21.3	22.4	23.9	25.3	26.7	27.6	27.6	27.0	25.3	22.8	20.9	24.3
Phoenix, USA	1981-2010	13.6	15.4	18.4	22.6	27.8	32.7	34.9	34.2	31.3	24.8	17.8	13.0	23.9
Houston, Texas, USA	1981-2010	11.7	13.6	17.1	20.8	25.0	28.0	29.1	29.3	26.6	22.0	16.9	12.5	21.0
San Antonio, USA	1981-2010	11.0	13.1	16.8	20.7	25.0	28.1	29.3	29.7	26.5	21.8	16.2	11.6	20.8
Tucson, USA	1981-2010	11.5	13.0	15.6	19.5	24.5	29.3	30.6	29.6	27.5	21.7	15.4	11.1	20.8
Durban, South Africa	1961-1990	16.6	17.7	19.3	20.4	21.8	23.5	24.5	24.6	24.0	21.8	19.2	16.8	20.8
Tel Aviv, Israel	1995-2009	13.7	13.9	15.8	18.6	21.3	23.9	26.2	26.6	25.4	22.8	19.3	15.7	20.2
Roma, Australia	1993-2012	11.9	13.7	18.0	21.6	24.5	26.2	27.4	26.3	24.2	20.2	15.6	12.7	20.2
Norfolk Island, Australia	1986-2005	16.2	15.9	16.7	17.9	19.0	20.8	22.1	22.5	21.8	20.3	18.9	17.1	19.1
Melbourne City, Australia 2090 RCP8.5	1986-2005	13.7	14.5	16.4	18.3	20.3	22.6	24.1	24.4	22.4	19.6	16.9	14.5	19.0
Los Angeles, USA	1981-2010	14.4	15.0	15.9	17.3	18.8	20.7	23.0	23.5	22.8	20.3	16.9	14.2	18.6
Sevilla, Spain	1971-2000	10.6	12.3	14.7	16.4	19.8	23.9	27.4	27.3	24.6	19.6	14.7	11.8	18.6
Perth, Australia	1986-2005	13.1	13.3	14.8	16.5	19.8	22.4	24.6	24.8	23.1	20.0	16.6	14.1	18.6
Sydney, Australia	1986-2005	13.2	14.3	16.6	18.6	19.8	21.9	23.0	23.1	21.6	19.4	16.6	14.0	18.5
Tunis-Carthage, Tunisia	1961-1990	11.5	12.0	13.2	15.6	19.3	23.2	26.3	26.8	24.4	20.4	15.9	12.5	18.4
Casablanca, Morocco	unknown	12.2	14.7	16.7	16.2	19.1	21.5	23.2	24.0	22.4	18.6	15.7	15.3	18.3
Jerusalem, Israel	1995-2009	9.9	10.5	13.1	16.8	21.0	23.3	25.1	25.0	23.6	21.1	16.4	12.1	18.1
Tacna, Peru	unknown	14.6	14.6	15.5	17.1	18.7	20.4	21.8	22.4	21.7	19.4	17.0	15.6	18.2
Tijuana, Mexico	1971-2000	14.0	14.7	15.1	16.2	18.5	20.5	22.8	23.0	22.3	19.3	16.5	13.8	18.0
Buenos Aires, Argentina	1961-1990	11.2	13.1	14.4	17.8	20.6	23.3	25.4	24.1	21.7	18.2	14.7	11.6	18.0
Fresno, CA, USA	1981-2010	8.1	10.9	13.7	16.7	21.2	25.1	28.4	27.6	24.6	19.1	12.4	8.0	18.0
Ismir, Turkey	1938-2000	8.9	9.7	11.5	15.8	20.5	25.0	27.5	27.3	23.7	19.1	14.5	10.8	17.8
Algiers, Algeria	1976-2005	11.1	11.7	13.2	14.9	18.1	22.2	25.1	26.0	23.6	20.1	15.3	12.6	17.8
Toowoomba, Australia	1996-2015	11.5	13.1	16.4	18.7	20.4	22.0	22.8	22.3	21.1	18.3	14.8	12.2	17.8
San Diego, CA, USA	1981-2010	13.9	14.4	15.3	16.5	17.8	19.2	21.2	22.0	21.4	19.3	16.3	13.7	17.6
Warwick, Australia	1994-2013	10.5	11.6	15.4	18.1	20.7	22.5	23.5	23.1	21.2	18.1	13.9	11.6	17.5
Athens, Greece	1955-1997	8.9	9.5	11.2	14.9	20.0	24.7	27.2	27.0	23.3	18.4	14.0	10.5	17.4
Melbourne City, Australia 2090 RCP4.5	1986-2005	12.2	13.0	14.8	16.7	18.7	20.9	22.4	22.7	20.7	17.9	15.2	13.0	17.4

Location	Climate Period	M1 (Win)	M2 (Win)	M3 (Spr)	M4 (Spr)	M5 (Spr)	M6 (Sum)	M7 (Sum)	M8 (Sum)	M9 (Aut)	M10 (Aut)	M11 (Aut)	M12 (Win)	Annual Average
Adelaide (Kent Town)	1986-2005	11.5	12.3	14.4	16.5	19.2	21.1	22.7	23.1	20.6	17.6	14.7	12.4	17.2
Dubbo, Australia	1993-2012	9.2	10.4	13.6	16.9	20.9	23.4	25.5	24.6	21.5	17.4	13.2	10.3	17.2
Montevideo, South America	1961-1990	11.1	12.0	13.6	16.0	19.0	21.4	23.2	22.7	20.9	17.5	14.4	11.4	16.9
Lisbon, Portugal	1961-1990	11.4	12.3	13.8	15.1	17.4	20.2	22.4	22.8	21.7	18.5	14.5	11.9	16.8
Cape Town, South Africa	1961-1990	12.3	12.7	14.0	16.0	18.4	19.9	20.9	21.1	19.8	17.5	14.9	13.0	16.7
Gawler, South Australia	1986-2005	10.3	10.8	12.7	15.0	18.4	20.9	22.5	23.0	20.2	17.0	13.8	11.3	16.3
Melbourne City, Australia 2030 RCP4.5	1986-2005	11.4	12.2	14.1	16.0	18.0	20.1	21.6	21.9	19.9	17.1	14.4	12.2	16.6
Santa Barbara, USA	1981-2010	13.1	13.8	14.4	15.8	16.7	18.0	19.8	20.1	19.6	18.1	15.3	13.2	16.5
Melbourne City, Australia (1986-2005)	1986-2005	10.8	11.6	13.4	15.3	17.3	19.3	20.8	21.1	19.2	16.4	13.7	11.6	15.9
Barcelona, Spain	1971-2000	8.9	10.0	11.3	13.1	16.3	20.0	23.1	23.7	21.1	17.1	12.6	10.0	15.6
Santiago, Chile	Unknown	9.4	10.8	12.6	15.3	17.8	20.2	21.4	20.8	18.8	15.6	12.5	9.8	15.4
Kunming, China	1961-1990	8.3	10.0	13.0	16.3	19.3	20.1	20.4	19.9	18.4	15.9	12.1	8.8	15.2
Marseille, France	1971-2000	7.1	8.3	10.7	13.1	17.4	21.1	24.1	24.0	20.4	16.0	10.8	8.1	15.1
Santa Rosa, USA	1981-2010	9.5	11.3	12.7	14.2	16.3	18.8	19.6	19.8	19.6	17.3	12.7	9.4	15.1
Washington, USA	1961-1990	1.4	3.1	8.4	13.7	19.2	24.3	26.7	25.8	21.8	15.4	9.9	4.1	14.5
San Francisco, USA	1981-2010	10.7	12.1	12.9	13.4	14.3	15.3	15.7	16.4	17.0	16.4	13.7	10.9	14.1
Monterey, USA	1981-2010	10.6	11.5	11.8	12.3	13.7	15.2	15.8	16.4	16.2	14.8	12.6	10.8	13.5
Toulouse, France	1971-2000	5.8	7.2	9.3	11.4	15.4	18.8	21.7	21.7	18.6	14.3	9.1	6.7	13.3
Hamilton, Australia	1961-1990	8.2	9.1	10.5	12.0	14.2	16.6	18.4	18.8	17.0	14.0	11.1	9.0	13.2
Paris, France	1971-2000	4.7	5.5	8.5	10.8	14.8	17.6	20.0	20.0	16.7	12.5	7.9	5.7	12.0
Christchurch, NZ	1981-2010	5.8	7.2	9.4	11.5	13.5	15.8	17.3	16.8	15.0	12.0	9.0	6.4	11.6
London, UK	1981-2010	5.6	5.7	8.1	10.3	13.5	16.4	18.6	18.5	15.7	12.2	8.6	5.9	11.6
Wellington, NZ	1981-2010	6.9	7.4	8.8	10.0	11.4	13.5	14.7	14.8	13.5	11.5	9.7	7.9	10.8

Data is sourced and adapted from World Meteorological Organisation, World Weather Information Service[69] and Climate Data Online, Bureau of Meteorology[70], Melbourne Regional Office.

[6*] Seasons have been aligned to match both northern and southern hemispheres.

APPENDIX 5 – IDENTIFYING MATCHING CLIMATES AND PLANTS AT RISK

The Köppen-Geiger climate classification is one system that is used to define climate types around the world. However, there are issues in seeking to apply these to locations with an equivalent climate to Melbourne. For example, under the current classification, Wellington, New Zealand and London, UK are classified the same as Melbourne's Cfb type (C = warm temperate climate, f = fully humid, b = warm summer); however, those locations do not share the same extremes of high temperature or dry conditions.[71]

Climate models are often quite broad and do not account for mesoclimate and microclimate differences or for situations such as a change in altitude or localised environmental conditions. For example, within a desert or Mediterranean climate type, mountains may occur and the montane flora will be adapted to quite different temperature and rainfall regimes compared to the lowlands. Or, a species growing in an arid climate may only occur in riparian zones or on the coast, subject to cooling sea breezes.

There are living specimens in Melbourne Gardens that when assessed against the climate of their natural habitat or realised ecological niche[72] are expected to perform poorly when exposed to extremes of high temperature and water scarcity; however, they have demonstrated surprising tolerance, particularly during some of the hot and dry extremes over the last decade. This may be an expression of the potential niche they could occupy. Effective plant selection of these taxa is also limited by poor understanding of the physiological or morphological mechanisms that provide them with this resilience[73], and/or how they might respond in cultivation. In addition, some phenotypes and/or taxa from different provenances may fare better than others in the future. The risk is that these and other species, although they positively contribute to the landscape, may be rejected for selection in a future climate, even though they might be quite tolerant. From a plant conservation perspective, it is also valuable to understand the potential niche of species in informing the level of risk from climatic change. Consequently, plant selection methodologies should seek to incorporate assessments of realised versus potential ecological niche.

Figure 27 *Libocedrus plumosa* – cool climate New Zealand conifer – has shown surprising resilience under water scarcity and heat wave conditions.

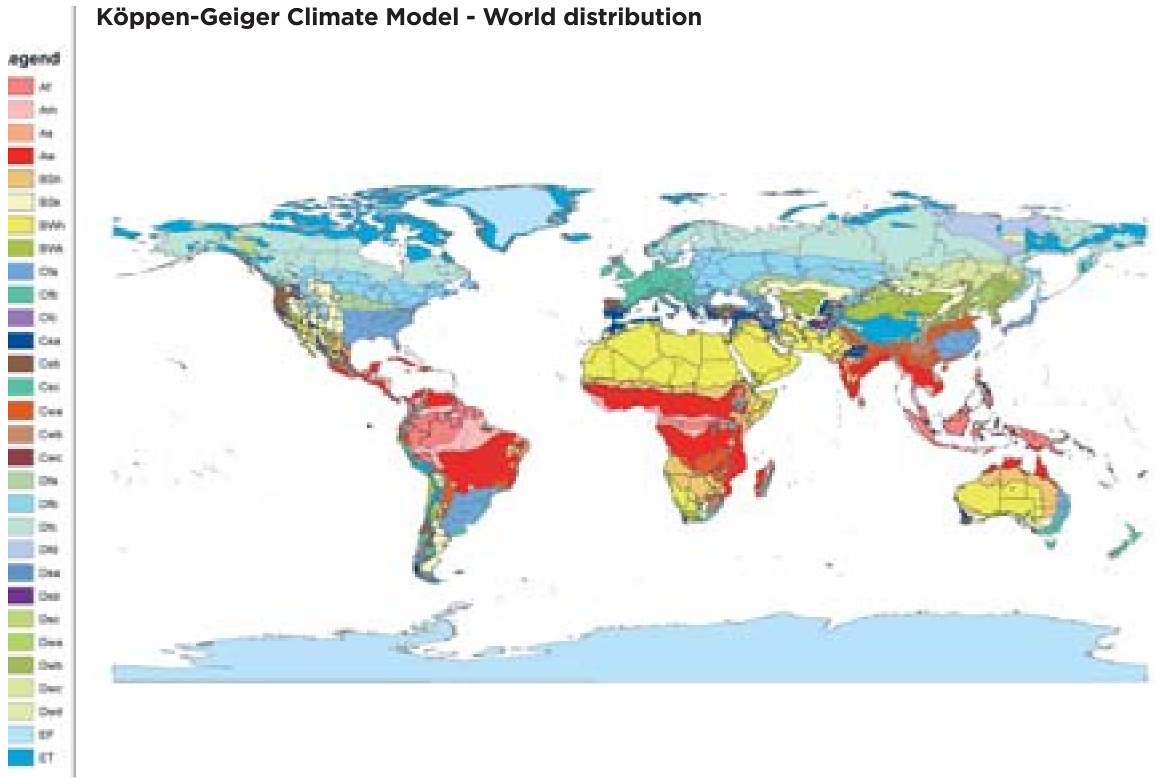


Figure 28 World Map of the Köppen-Geiger climate classification

APPENDIX 6 – LIVING COLLECTIONS PLANT DATABASE GENERATION OF MAP FOR CSA CLIMATE TYPE

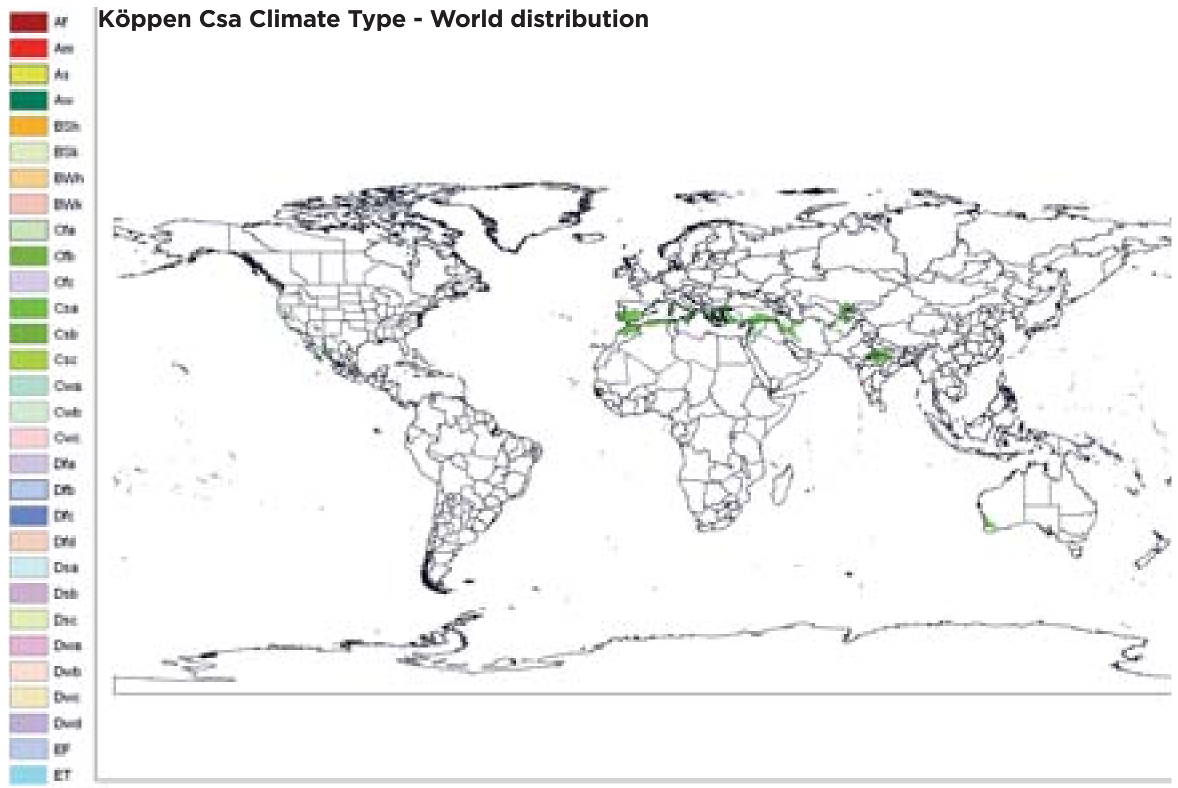


Figure 29 Basic Recording Units (BRU) are shown as areas with black boundary lines. BRUs are often limited to country borders, which are too large in extent to cross-match plant distribution with climate type.

APPENDIX 7 – MELBOURNE GARDENS – ANNUAL RAINFALL[7*] ANOMALIES FOR 1856 TO 2015

[7*]Calculated on the basis of comparing whether each consecutive year was above or below average in annual rainfall. A series of years with above average rainfall would accumulate a positive anomaly (blue bars). The converse is shown as black bars in the graph.

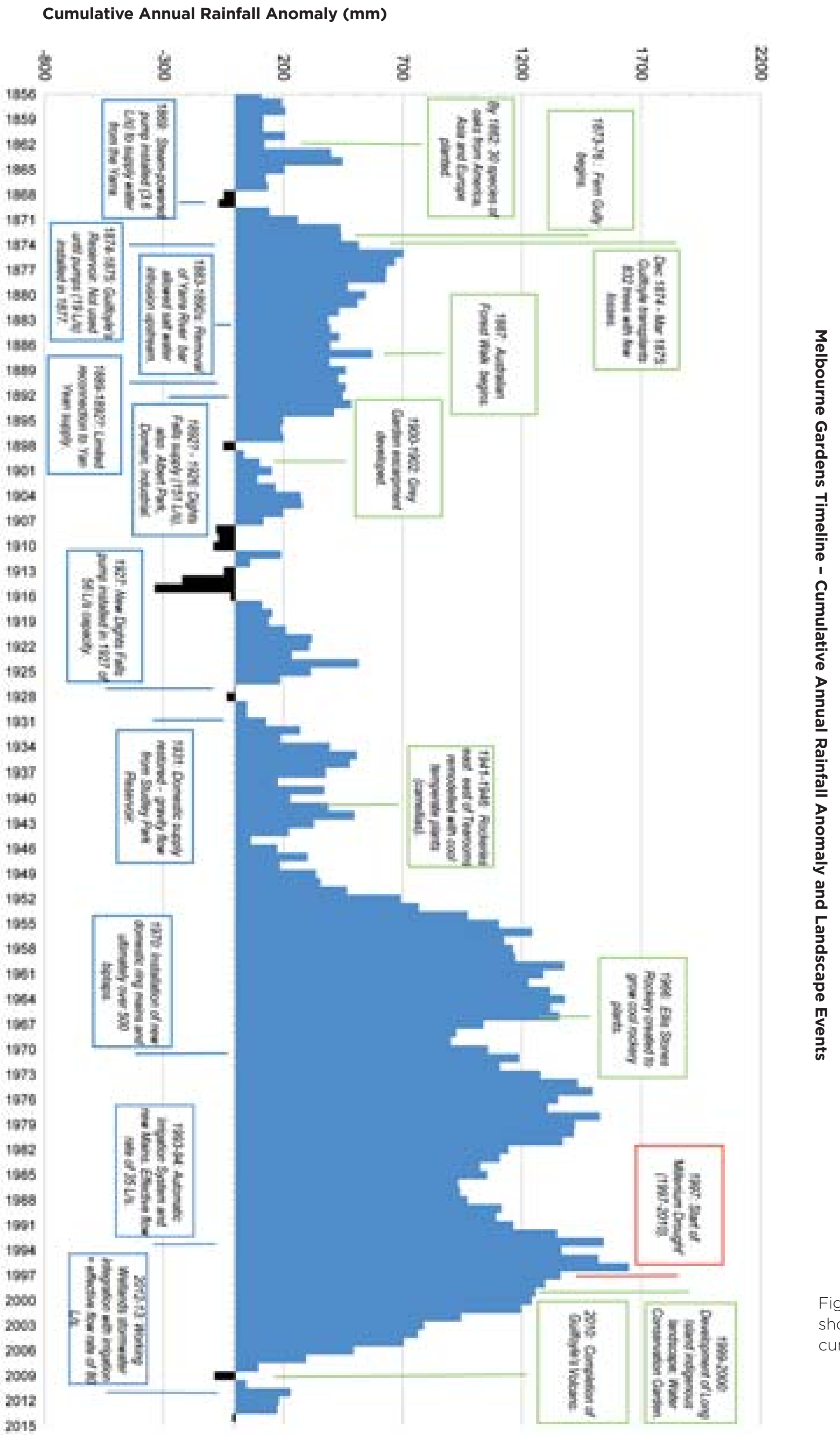


Figure 30 Melbourne Gardens timeline showing landscape development and cumulative annual rainfall anomaly

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