HOW ARE BOTANIC GARDENS IN THE COMMONWEALTH OF AUSTRALIA AND THE UNITED STATES OF AMERICA MANAGING THE RISK TO LIVING PLANT COLLECTIONS IN THE EVENT OF WATER SHORTAGE?

by

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ABSTRACT

Given the time, money and effort expended in the acquisition, establishment, curation and maintenance of a living botanical collection, and the irreplaceable nature of some living collections, it would be reasonable to assume that these living assets would be secured against loss. Using broad survey and in-depth interviews with gardens in the United States and Australia, this research considers what botanic gardens can do to protect their living collections in the face of water shortage.

This research found two major approaches to managing living collection in the face of water shortage, managing the collection, and managing the water. A third important component was managing stakeholder expectations; with education and good communication essential to achieving a transition to active collections management in the face of water shortage. Gardens were more likely develop plans to manage water shortage if they have faced shortage previously. Plans ranged from simple prioritizing of collections for watering, to complex, multi-million dollar 'drought proofing' systems developed over many years In Australia, the rising cost of water was found to be a driver for some gardens to initiate schemes to reduce water use and assess the suitability of living collections in the face of climate change.

Using the experience and observations of botanic gardens that participated in this research, and a review of current practices in allied fields such as sports turf management, a 'how to' guide was developed to assist gardens in planning for water shortage.

UNITS OF MEASUREMENT AND CURRENCY

The metric system is used throughout this document; the imperial equivalent is given where clarity is required. Where monetary cost is mentioned, the currency is that of the country referred to. For example, if a dollar amount is quoted in a section discussing Australian gardens, the currency quoted is AUD$. Likewise the United States examples are quoted in USD$.

Chapter 1

INTRODUCTION

Botanic gardens and arboreta are repositories of documented living plant collections. They are also places of beauty, cultural value (Askwith 2000), and often have such significant heritage value that they are listed on registers locally, nationally, or internationally. Kew Gardens, Singapore Botanic Gardens and Botanical Gardens Padua are all inscribed on the UNESCO World Heritage List. To meet Botanic Gardens Conservation International's (BGCI) criteria to be considered a botanic garden, an institution's plant collections must meet a range of criteria, including having a reasonable degree of permanence, proper documentation of the collection, adequate labeling, and associated research programs. "*Botanic gardens are institutions holding documented collections of living plants for the purpose of scientific research, conservation, display and education*" (BGCI 2015a). BGCI estimates there are more than 3,300 botanic gardens and arboreta across the world.

Activities undertaken by botanic gardens may include public programming and events, publishing, community programs, taxonomic and ecological research, *in situ* and *ex situ* plant conservation programs, and horticultural programming and displays. An arboretum is a botanical collection of trees, meeting the same criteria as a botanic garden in terms of documentation, labeling and research. In this thesis, the term 'botanic garden' includes arboretums. Excluded from this research were public parks, private gardens and public display gardens unless they demonstrated accordance to the above definition of 'botanic garden'.

The maintenance of living collections in botanic gardens and arboreta requires a range of skills, techniques and environmental manipulation (Rae 2014). Periods of drought accentuate the effort required to maintain living plant collections in botanic gardens and arboreta, with additional water, staff time and funds often required to keep collections alive. Drought highlights competing priorities and interests between water utilities, water intensive industry and agriculture, domestic customers, recreational users and botanic gardens and arboreta. Public policy can change at short notice during periods of water shortages, and public gardens are not immune to the imposition of water restrictions. Moreover, living collections generally require supplementary irrigation even during years of normal rainfall, and thus are vulnerable to interruptions to water supplies even when drought is not an implicit threat. As the cost of water increases, botanic gardens also must balance the needs of their plant collections against the financial and environmental cost of the water required to maintain them.

A reliable and secure water supply is a fundamental requirement for the viability of any botanic garden. A literature search has revealed no detailed reports of the impacts on major botanic gardens or public gardens in the USA or Australia arising from severe water restrictions imposed. There has been internal analyses of water efficiency undertaken by Australian Botanic Gardens – for example Melbourne Gardens (Peter Symes. 2016, Pers. Comm.) and Adelaide Botanic Garden (Andrew Carrick. 2015, Pers. Comm.) have produced operational and policy documents pertaining to drought management. Adelaide Gardens has appraised its living collection to determine climatic suitability and de-accessioned some collections because they have been deemed unsustainable for Adelaide's current and future climate (John Sandham. 2012, Pers. Comm.). Except for Melbourne Garden's Landscape Succession Strategy (Royal Botanic Gardens Victoria 2016), these documents have not been published, nor has it been presented at conferences or symposia.

RESEARCH GOALS

The researcher's interest in this topic arose from the experience of working in botanic gardens and heritage gardens that were subject to severe water restrictions in 2004, at the height of a prolonged drought on the east coast of Australia. There is an absence of published data in Australia and the U.S. concerning strategies to manage existing and future living collections under threat from water shortages. There is also very little published data on the impact on living collections from previous episodes of water shortages in botanic gardens.

The research question this thesis poses is "How are Botanic Gardens in Australia and the United States managing the risk to their living collections posed by the threat of water shortage?" The thesis will explore to what extent water shortage is seen as a risk to collections; how prepared botanic gardens are to manage cyclical water shortages and water restrictions; and what strategies are being used to reduce the impact of water shortage on living collections in botanic gardens. The research also explored if there is any particular kind of collection that is more likely to generate a risk management plan for water shortage. The aim is to compile a checklist that botanic gardens can use to assist in undertaking the risk assessment, and preparing a plan to manage water shortage.

The Evolution Of Botanic Gardens In Australia And The United States

By the close of the Victorian era, Britain, generally with the close oversight of Kew Gardens, had overseen the founding of more than 120 botanic gardens in its far-flung empire, including gardens in the West Indies, Australia, Africa, Canada, Singapore and India (McCracken 1997). Initially set up for the purpose of testing, growing and distributing recently discovered economic plants; the location of these gardens was usually dictated by proximity to the administrative center of the colony. Some of the world's great public gardens and living collections were established in the 18th and 19th centuries in the new colonies; for example, the Royal Botanic Gardens Sydney, established in 1816, developed its renowned Southern Hemisphere tree collection during the tenure of peripatetic 19th century Directors Fraser, Cunningham and Moore (Gilbert 1986). These gardens hold eclectic and important collections; 11% of the world's endangered and uncommonly grown gymnosperm taxa, for example, is held in just seven Christchurch, New Zealand regional gardens (Arnet et al. 2015).

Australia has approximately 90 botanic gardens and arboreta, ranging from regional, volunteer-led gardens such as the Illawarra Grevillea Park near Wollongong in NSW, to the large, state-funded, gardens in Sydney, Melbourne and Canberra. Australia's major state botanic gardens are all located adjacent to their city centers, an artifact of each state's British Colonial Governor preserving land as 'Domain', parts or all of which sooner or later became botanic gardens, including the Royal Botanic Gardens (RBG) Sydney (established as a botanic garden in 1816), Royal Tasmanian Botanical Gardens (1818), the RBG Melbourne (1846), City Botanic Gardens Brisbane (1855), Adelaide Botanic Garden (1857), and Kings Park and Botanic Garden (1872). Each of these state gardens hold living records of colonial plant explorations, and are sites of significant cultural heritage. Sydney, Melbourne, Adelaide and Brisbane Botanic Gardens have also established gardens at other locations in addition to their city center campuses. The Australian National Botanic Garden in Canberra was founded in 1949, focusing on Australian plants from many parts of the country.

Botanic gardens in the United States developed in a different fashion to the colonial European empire gardens. Plant collectors, nurserymen and philanthropists developed America's earliest gardens. Bartram's Garden in Philadelphia was one of the first botanic gardens in the American colonies, established by John Bartram in 1728; the garden once boasted the largest collection of North American plants in the world (Bartrams 2015). In the U.S., Unlike Australia, philanthropists founded many of the great gardens; most of which still operate as not-for-profit foundations. Missouri Botanical Garden was a gift of businessman Henry Shaw, who founded the garden in 1859, collaborating with distinguished botanists of the day to create the foundation of what is today one of the world's leading botanic garden (Missouri Botanical Garden 2015). Pierre S. DuPont founded Longwood Gardens, one of the world's pre-eminent display gardens, in 1906. The United States Botanic Garden in Washington DC was established under the guise of government direction and become a repository and distribution center for the exotic collections acquired during Wilke's voyage across the Pacific, and later, Perry's exploration of Japan, China and South East Asia in the mid 19th century (Fallen and others 2006). The United States now has approximately 600 botanic gardens and arboreta. Table 1.1 illustrates the chronology of botanic gardens development in the British Commonwealth and in the United States.

Table 1.1 The chronological context of Botanic Gardens development in Australia and the United States.

Garden	Date		Garden	Date
Orto Botanico di Pisa	1543		Singapore B.G.	1859
Oxford Physic Garden/ B.G	1621		Kings Park Perth	1872
Edinburgh Physic Garden/ B.G	1670		U.C. Botanic Garden Berkeley	1890
Chelsea Physic Garden	1673		New York Botanic Garden	1891
Bartrams Garden	1728		Longwood Gardens	1906
RBG Kew	1759		Matthaei Botanical Gardens	1907
Rio de Janeiro B.G.	1808		Vizcaya Gardens	1921
RBG Sydney	1816		Fairchild Tropical B.G.	1938
Royal Tasmanian B.G.	1818		ANBG Canberra	1949
RBG Melbourne	1846		San Diego B.G.	1961
Brisbane B.G.	1855		Wollongong B.G.	1970
Adelaide B.G.	1857		Blue Mountains B.G.	1972
Missouri B.G.	1859		Lady Bird Johnson Wildflower	1982

The Role of Botanic Gardens in ex situ Plant Conservation

Conservation of living plants through *in situ* protection of their native habitats is the most effective and efficient form of plant conservation (Kramer and Havens 2009). With expert opinion placing about one third of the world's plant species at risk of extinction (Oldfield 2010), the conservation value of documented living collections growing in botanic gardens across the world is significant. As defined by E.H. Roberts (1973), recalcitrant seeds are those losing viability when desiccated to below 15% moisture. The value of ex situ living collections is accentuated for those plants with recalcitrant seeds; for example, the majority of palm species must to be conserved as living plants because the seed cannot be desiccated and stored (Griffith, Lewis, and Francisco-Ortega 2011). Additionally, many Eastern Australian rainforest species have recalcitrant seeds, precluding traditional desiccation seedbank storage (Hamilton et al. 2013).

The Global Strategy for Plant Conservation (GSPC), adopted by the parties to the Convention on Biodiversity in 2002, has five objectives and 16 targets. Target Eight is of particular relevance to botanic gardens, that target being to preserve at least 75% of threatened plant species in *ex situ* collections, being living collections of botanic gardens, in seed banks, *in vitro* collections, or in field gene banks. Well-documented, genetically representative plant collections contribute to Target Eight through research, propagation material, education, and restoration programs (Sharrock 2012). Furthermore, collections based horticultural research, including phenology trends, germination studies and pollination processes (Donaldson 2009) rely on well-curated living collections. Oldfield (2009) for example, notes that conservation and regeneration of threatened Magnolia species in the wild would be assisted by research into the reproductive biology and the development of propagation techniques using garden collections.

Increasingly, botanic gardens are collaborating to leverage the impact of ex situ plant collections. The Plant Collections Network (formerly the North American Plant Collections Consortium), overseen by the American Public Gardens Association, aims to encourage a coordinated approach to plant germplasm conservation, promoting excellence in plant collections standards, expanding the diversity of existing collections, and identifying gaps for future collections. The Network has (as of January 2016) 75 participating gardens, 129 accredited plant collections and four multi-site collections. The Magnolia multi-site collection has hundreds of taxa, both species and cultivars at 17 geographically diverse participating gardens including Scott Arboretum at Swarthmore College near Philadelphia, Atlanta Botanic Garden and the University of California Botanical Garden at Berkeley. Other North American collaborative networks include BGCI North America, the Center for Plant Conservation, and the Plant Conservation Alliance.

Ad hoc germplasm exchange and sharing is not uncommon among the relatively small network of botanic gardens within Australia, however there is no organized ex situ plant collections network in place. The Australian Network for Plant Conservation functions as a clearing-house for information relating to the Australian plants, but does not have a plant collections focus.

Defining the Purpose of Living Collections

The living plant collections of contemporary botanic gardens range from the rigorously documented and purposeful collections of the Arnold Arboretum, to the flamboyant horticultural displays of the Dallas Arboretum and the regional flora collection of Mackay in Queensland. Collections can be loosely categorized under the four broad categories proposed by Botanic Gardens Conservation International (BGCI 2015b):

- Geographical Collections – a collection based on the flora of a particular area of the world.
- Taxonomic, or synoptic collections – based on taxonomic plant groups, for example, cycads, palms, Myrtaceae.
- Ecological Collections – plants from a single habitat or ecotype.

- Thematic collections – plants grouped by a particular characteristic, grown for education, science, conservation or horticultural display.

Whatever the thematic grouping, the basis of a well-curated collection is the living collections policy, a document that sets out the rationale and purpose of the collection, providing specific guidance as to how the collection is developed, including what may be acquired, and what may not. Montgomery Botanic Center's Plant Collections Policy notes that the Center 'carries out its mission by collecting seeds from wild populations of tropical plants from around the world, particularly seeds of palms and cycads' (Husby 2007, 1), and specifies precisely how the collection is organized, how it is selected, acquired and under what circumstances plants are disposed of. Rancho Santa Ana Botanic Garden will 'develop, assemble, document, maintain and exhibit a Living Collection of California plants' (Rancho Santa Ana 2007, 1). Booderee Botanic Gardens in New South Wales will 'assemble, display and interpret a representative collection of Australian plants focusing on south-east coastal flora… from Sydney to the Victorian Border, between the coast and the top of the escarpment of the Great Dividing Range' (Booderee Botanic Gardens 2003, 3).

A strategic approach to collections management is necessary to achieve excellent curatorial standards of living plant collections (Cavender et al. 2015; Dosmann 2008). Good collections curation is key to maintaining 'exemplary living plant collections' (Gates 2007), a critical element of which is keeping the plants in good health, and safeguarding important collections against loss, through duplication, seed storage and institutional succession planning (Gates 2007, 57-58).

Fountain et al (2010) refer to the 'idiosyncratic' development of living collections in older botanic gardens. These collections, including the legacy collections of Colonial gardens, in some cases acquired over decades or centuries, often without a clear collections strategy, can be difficult or impossible to replace, due to financial constraints, lack of replacement material, and the inability to secure appropriate acquisition agreements and permits. Proper appraisal of the scientific and cultural value of such collections is imperative in order to build sound collections management strategies, including which collections to save in the event of an acute or chronic water shortage.

Chapter 2

LITERATURE REVIEW

PLANNING FOR DISASTER IN BOTANIC GARDENS

The International Council of Museums (ICOM) defines a museum as an institution "*which acquires, conserves, researches, communicates and exhibits the tangible and intangible heritage of humanity and its environment for the purpose of study and enjoyment"* (International Council of Museums 2007). Since the central purpose of a botanic garden is to hold "*documented collections of living plants for the purpose of scientific research, conservation, display and education* (BGCI 2015a) a botanic garden could be considered a museum of living plants. Twenty-one botanic gardens have received accreditation from the American Alliance of Museums, after meeting standards in accountability, mission and planning, leadership, collections stewardship, education, financial stability and facilities and risk management. One of the five documents required for accreditation is the disaster preparedness/emergency response plan, which must specify how to protect, evacuate, or recover collections in the event of a disaster (American Alliance of Museums).

The disaster planning process enables museums and botanic gardens to assess their collections and prioritize the most important components. A disaster plan will create scenarios to examine and test the most likely or the most damaging disasters, and will document how to deal with them. The International Council of Museums (ICOM) notes that 'disaster' and 'emergency' are not the same things. Disaster is a longer term or widely spread event, whereas an emergency is a more common interruption to normal operations (International Council of Museums 1993). 'Disaster' in museum terminology is usually an unexpected event, but generally one that has been assessed as a having a possibility of occurring, with the assessment of risk based on previous events, weather records or the experiences of other organizations. A museum disaster may stem from fire, weather, earthquake, flooding, social disruption or other causes, and can potentially cause long-term interruption to normal operations. A robust disaster plan will identify threats to collections, take steps to reduce the risks, and outline how to deal with a disaster if it does happen.

Disasters in botanic gardens may stem from similar hazards as those in museums. The Plant Collections Network of the American Public Gardens Association states it is 'desirable' to have back up replicates and long term germplasm storage as part of its plant collections accreditation process, but does not require a plan to manage the impact of natural disasters as yet (Pamela Allenstein. 2016, Pers. Comm.)

Berghardt (2000) examined the perceptions of natural disaster in United States public gardens in his Master of Science thesis. Twenty percent of the horticultural institutions said ice storms were the most damaging or disruptive natural disaster, more than any other event, with drought nominated by 6% of surveyed institutions. Notwithstanding the tremendous damage caused by natural disasters, only 38% percent of 201 American gardens surveyed had a plan to manage natural disasters.

Bergquist developed a disaster plan template for her Master of Science thesis. Of the 200 American gardens surveyed by Bergquist (2009), 60% had a disaster plan, but less than one third of those gardens with disaster plans had information in their plans about how to deal with living plant collections. Gapinski's thesis on preparing plant collections for biological invasions noted that of the nine case study gardens whose *Fraxinus* collections were threatened by the impending arrival of emerald ash borer, only one had a disaster plan in place which addressed any kind of threat to its living collection (Gapinski 2010). The rapid loss of much of the *Fraxinus* collection at the Matthaei Botanical Gardens and Nichols Arboretum upon the arrival of emerald ash borer highlighted the vulnerability of living plant collections to external threats, and the importance of having a plan in place to minimize loss of valuable material (Michener 2008).

Hurricane Andrew damaged or destroyed much of Fairchild Tropical Botanic Gardens' palms, cycads and trees in August 1992, the difficult salvage operation made somewhat easier because the plant records system remained intact (Evans 2003). Not so lucky in that respect was New Orleans Botanic Gardens, which not only lost its entire plant collection to post-Hurricane Katrina flooding, but the extent of the loss will never be quantified because the garden's plant records were also lost in the flood (Susan L. Capley. 2015, Pers. Comm.). Evans' review of the aftermath of Hurricane Andrew listed key components of a successful disaster response. Having a "clear plan" of action was critical; and a thorough knowledge of the collection enabled staff to prioritize saving the most important trees, palms and cycads. Accurate and current plant records assisted in the identification of which specimens were significant. To manage future disasters, a "Hurricane Manual" was written, using the experience from Hurricane Andrew as a guide (Evans 2003).

Montgomery Botanical Center near Miami, Florida also has a disaster plan specifically to manage hurricane damage (Montgomery Botanical Center 2005). Developed in the aftermath of Hurricane Katrina, the protocols were used just two months later to manage the damage from Hurricane Wilma. The procedures ensure preparedness for hurricane, including having material stockpiled to rescue and protect fallen palms and cycads before each hurricane season.

The ability to determine which plants in a collection to prioritize for rescue in the event of a disaster is greatly enhanced if that collection has a well-defined plant collections policy, and the plant data is current and complete. Longwood Gardens has assigned priorities to all its living collection. The four level priority system has the highest priority given to plants that are impossible to replace because of rarity, age, historic, or scientific value. The lowest priority in the event of its loss is where the plant would not be replaced (Aguilar 2010). Between January 2009 and February 2010, horticulturists were tasked with inventorying their collections, and then assigning a priority to each accession. The work was undertaken as part of developing disaster planning protocols and procedures for the living collection. Longwood Gardens made this project a high priority, allocating staff resources to undertake the work to ensure its completion.

DROUGHT

The Australian Bureau of Meteorology calls drought a 'prolonged, abnormally dry period when the amount of available water is insufficient to meet normal use' (Australian Bureau of Meteorology 2016g). Drought takes longer than most natural disasters to manifest, it can take weeks, or months, rather than hours or days for drought to become apparent. However, once drought takes hold, events can occur rapidly. For some gardens, bushfires and or wildfire is an additional threat beyond that of soil moisture deficits and thirsty plant collections.

In Australia, droughts are a feature of the climate, but several remarkable droughts (even by Australian standards) have been the catalyst for changes to the way in which water is used. The Millennium Drought affected most of Australia from before the turn of the 21st century to 2009. Two exceptionally dry years interspersed with rainfall at or below average saw water deficits across most of the country. Figure 2.1 illustrates the extent of the rainfall deficit across Australia for the five consecutive 36-month periods between 2001 and 2016. Intervals of 36 months are used to illustrate the cumulative effect of this extended drought. There was only one three year period during this time where above average rainfall was experienced in the eastern states, and in south-west Western Australia, the drying trend has continued unabated. All of the State capital cities were impacted by this drought (i.e. Brisbane, Sydney, Melbourne, Hobart, Adelaide, Perth and Canberra). During this time, severe water restrictions were introduced in capital cities across the county, as well as regional areas of all the eastern states and South Australia.

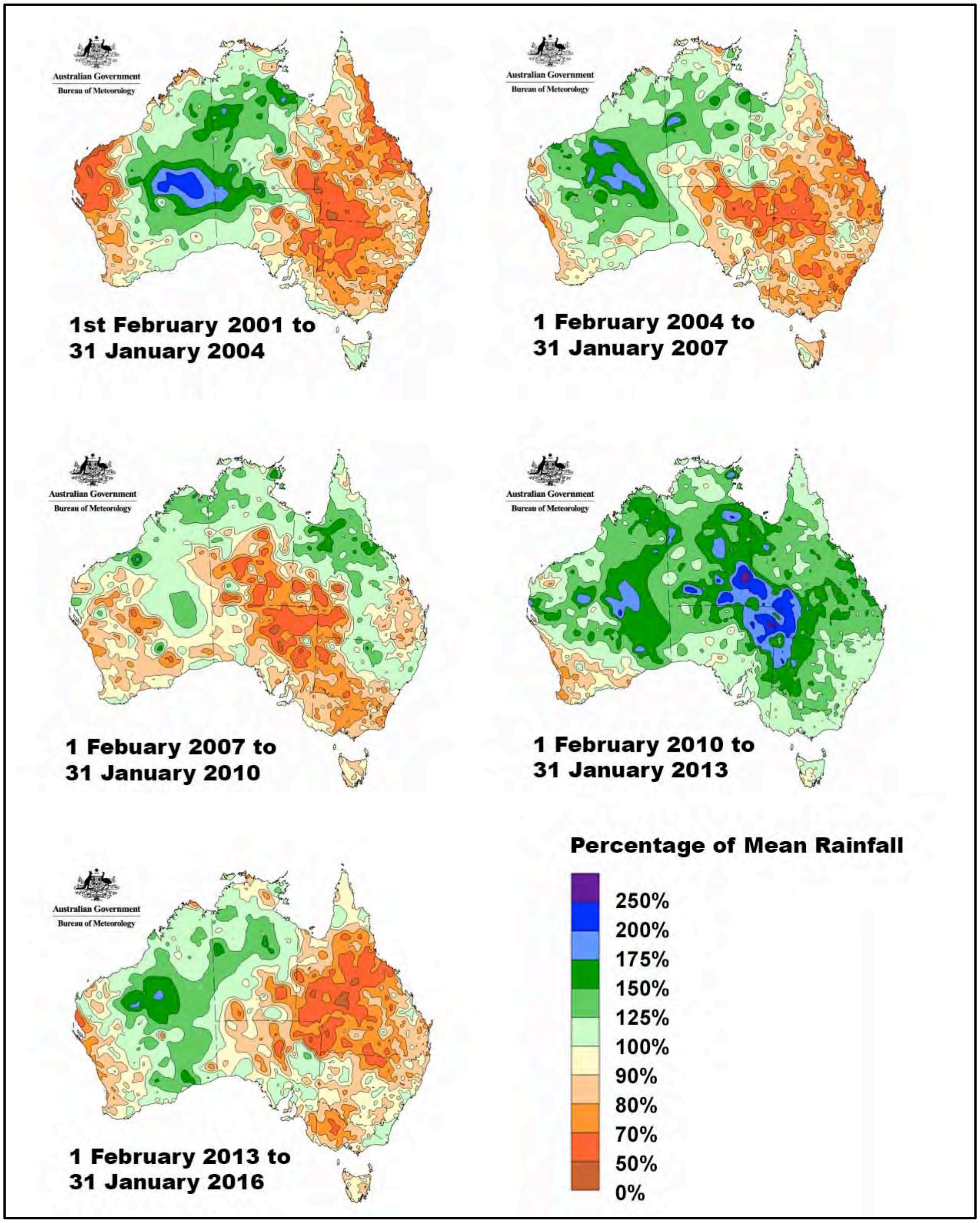


Figure 2.1 Percentage of average annual rainfall in Australia for each three-year period from 2001 to 2016. (Australian Bureau of Meteorology 2015a)

Berghardt's (2000) survey of American public gardens showed 79% had experienced drought in the period 1980-1999, and 60% had experienced drought more than once in that time. Notwithstanding that 85% believed they would experience drought in the future, few had any plans to deal with it.

California has been in drought since 2012, with 2014 being the third driest water year on record in that state. Furthermore, the 2015 snowpack, which much of the state relies on for replenishing reservoirs, was 5% of its normal depth. Water restrictions have been imposed across the state, with the goal of reducing consumption by 25%, compared with 2013 usage. Residential water use, in particular garden watering, has been curtailed in major population centers, with areas of greatest consumption being targeted for the most reduction, by 32% of 2013 water use in Ventura County, and 28% in Los Angeles County.

The U.S. Drought Monitor defines an exceptional drought as one where 'exceptional and widespread crop/pasture losses' occur, with 'shortages of water in reservoirs, streams and wells creating water emergencies', while extreme drought will lead to 'major crop/pasture losses' and 'widespread water shortages or restrictions' (National Drought Mitigation Center at the University of Nebraska-Lincoln 2016a). Since 2001, extreme or exceptional drought has been more frequent in the west and south of the country, however, some part of the contiguous United States has experienced extreme or exceptional drought each year, and most regions except New England have experienced at least one episode of severe, extreme or exceptional drought since 2001 (Figure 2.2).

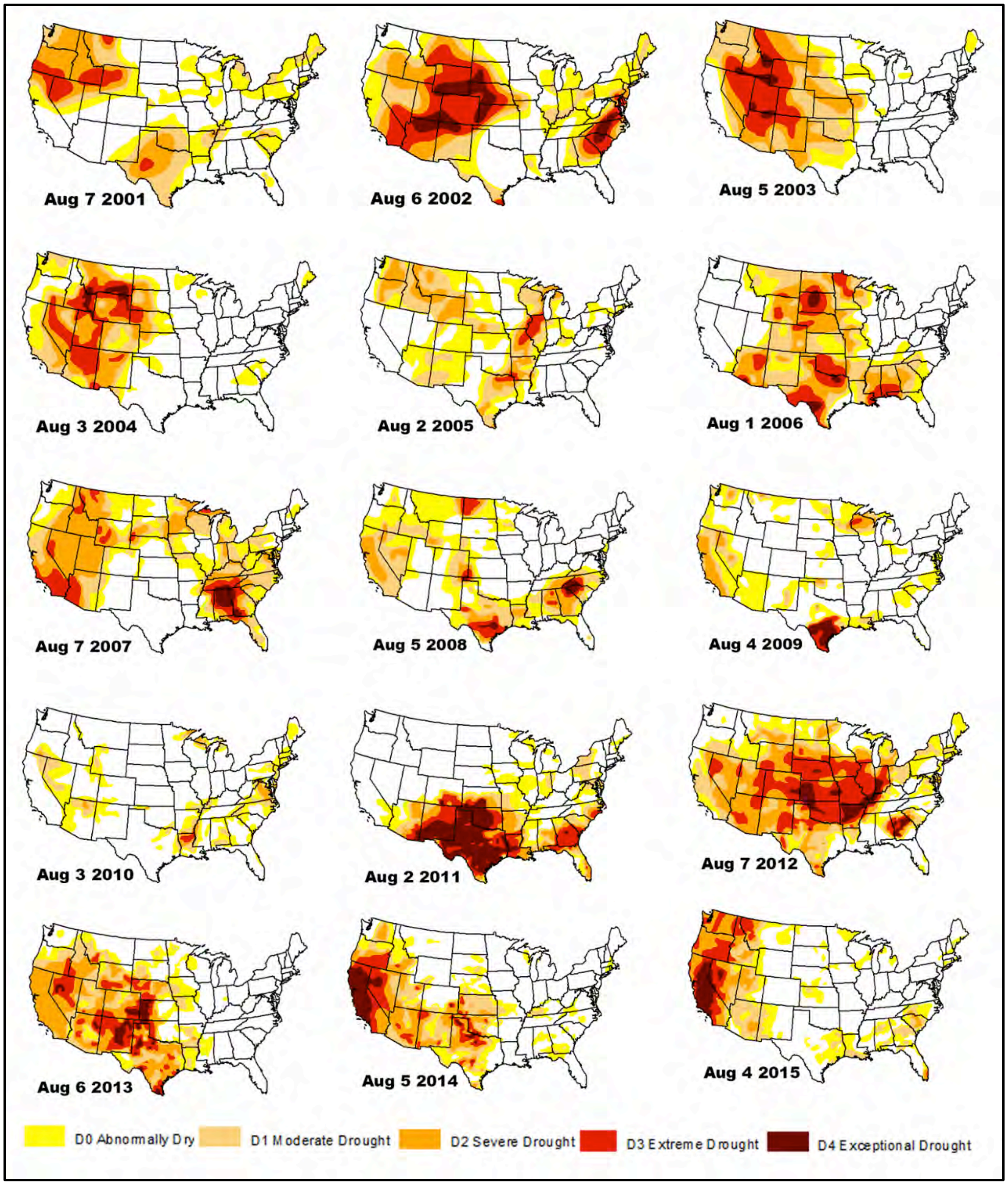


Figure 2.2 Area of drought in the United States in the first week in August since 2001. Source: Maps compiled from U.S. Drought Monitor, National Drought Mitigation Center at the University of Nebraska-Lincoln 2015a

WATER RESTRICTIONS

The Royal Botanic Gardens and Domain in Sydney (RBG Sydney) evolved on the site of Australia's first European farm adjacent to Farm Cove, part of Sydney Harbour. The British settlers of 1788 quickly discovered Australia's weather extremes. The El Nino Southern Oscillation is an important influence on the climatic conditions of the eastern third of Australia (Australian Bureau of Meteorology 2015). Gergis (2008, 103-107) reports that Australia's first documented water restrictions were implemented less than three years from the founding of the Colony, following a very strong El Nino event. More than 200 years later, the Millennium Drought saw severe water restrictions imposed across Sydney, in 2004, the RBG Sydney's water consumption fell by two thirds at the height of the drought when Sydney Water restricted its water use to hand-watering before 10am each day. This situation overwhelmed the staff at the Gardens; valuable accessions were lost partly because there was no clear decision system in place as to which collections and individual plants to water, and which ones could be sacrificed (Simon Goodwin. 2014, Pers. Comm.).

New York City has in the past imposed water restrictions during declared drought emergencies, severely limiting the amount of water that can be used on gardens. In late March of 1989, watering of all ornamental plants was abruptly prohibited by the City of New York in response to a declared drought emergency. The attempts by the Metro Hort Group to negotiate with the City were futile, the impasse being broken only by fortuitous drought-breaking rain (Britton and Murbach 1990). The New York Botanical Garden installed a multi-million dollar non-potable irrigation system to ensure its collections would no longer be severely impacted by water shortages, after losing important collections, including venerable trees, to a series of droughts in the 1990's to mid 2000's (Forrest 2005).

Studies and the reports of the effects of drought and water restrictions on turfgrass and sport seem to be more prevalent than the impacts of drought on botanic gardens living collections. In Australia, where high cultural values are placed on viewing professional sports and participating in community sport (Burgin, Parissi, and Webb 2014, 154-166), the literature reveals, for example, concern with the condition of sporting fields and the impacts on sporting teams from drought-induced hard playing surfaces (Phillips and Turner 2013), sport played under hotter conditions (Climate Institute 2015), and the socio-economic impacts of sports turf water restrictions (Weller and English 2008). In the U.S., managed turfgrass is estimated to be a $100 billion industry, occupying about 2% of the surface of continental United States (Emmons and Rossi 2016). Not surprisingly there is a plethora of research on managing turfgrass in the face of water shortage, including the impacts of using recycled water on turf grasses (O'Connor, Elliott, and Bastian 2008), (Marcum 2006), (Evanylo, Ervin, and Zhang 2010).

Stern's (2010) Master of Science thesis focused on the role of U.S. and Australian public gardens in promoting water-wise landscaping. This thesis did not explore how public gardens were practicing water-wise landscaping, but rather, how they were communicating the concept to the public.

Not surprisingly however, Stern found that gardens in the west and south of the United States placed higher importance on water conservation than gardens in the Midwest or north east, but overall, 45% of the 127 public garden respondents said water conservation in their own institutional operations was ‘very important’, with a further 38% stating it was ‘moderately important’.

CLIMATE AND CLIMATE CHANGE

Australia is the driest inhabited continent in the world, with three quarters of its landmass being either arid or semi-arid. Australia’s annual and seasonal rainfall varies considerably, with drought and flood events influenced by complex climatic interactions, including the El Nino Southern Oscillation (Beeton et al. 2006). El Nino also impacts U.S. weather, with correspondingly wetter than average weather often (but not always) experienced in the south west of the U.S. when Australia is affected by drought. For example, heavy flooding and landslides in California in 1982/83 and 1997/98 (Halpert 2014) coincided with two of Australia’s more severe droughts.

The Intergovernmental Panel on Climate Change (IPCC), the United Nations scientific organization for the assessment of climate change was established in 1988. The IPCC’s Fifth Assessment Report was produced by more than 830 authors and editors from over 80 countries, based in turn, on the work of more than 1,000 contributing authors and approximately 2,000 expert reviewers (IPCC 2015). The IPCC concluded, “Surface temperature is projected to rise over the 21st century under all assessed emission scenarios. It is very likely that heat waves will occur more often and last longer, and that extreme precipitation events will become more intense and frequent in many regions. The ocean will continue to warm and acidify, and global mean sea level to rise” (Pachauri, Meyer, and Core Writing Team 2014, 10). Four greenhouse gas emissions scenarios were used in compiling the Report, ranging from a scenario where greenhouse gases were strictly controlled (RCP2.6), to a scenario where emissions continue to remain high (RCP8.5).

Climate change is projected to lead to increased temperatures in the US and Australia, and lead to changes in precipitation in both countries. Higher air temperatures increase the evaporation rate, and hence surface water loss, and also lead to an increase in the evapotranspiration rates of plants, with a commensurate increase in the amount of water required to keep them alive.

Predicted changes in precipitation vary across the US, with a decrease in some regions and an increase in others. A reduction in the level of snowpack, and the timing of snowmelt is expected to impact the northwest (Mote et al. 2014) and southwest regions of the U.S (Garfin et al. 2014). Snowpack is an important water resource, the melting snow regulating streamflow through spring and summer, as well as insulating the ground and holding soil moisture. Earlier snowmelt can lead to spring flooding, and lower streamflows in summer and autumn. Groundwater recharge is predicted to decrease in the southwest region, and demand will increase for water resources from the High Plains Aquifer system, underlying parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas and Wyoming (McGuire 2013). Competition for water in the northwest is also expected to intensify, with demand from agriculture, industry, environmental protection and municipal use increasing (Mote et al. 2014). Increased temperatures will increase seasonal drought in the northeast, and initiate earlier snowmelt (Horton et al. 2014). It is projected that some areas of the central Great Plains and most of the southern central states will experience drier summers (Shafer et al. 2014). Overall, annual runoff and river flow is projected to decrease in the Southwest southern Great Plains and Southeast, and the incidence of long-term drought is also projected to increase in these regions. Although annual precipitation is projected to increase in all regions except the south, most regions of the US except the far northeast and Great Lakes are expected to have an increase in summer droughts due to higher temperatures and longer dry periods (Georgakakos et al. 2014). Figure 2.3 shows the predicted change to average surface air temperatures in the century from 1999 to 2099. Even under lower emissions scenario, temperatures will increase by 2.7 degrees C in some regions of the contiguous 48 states.

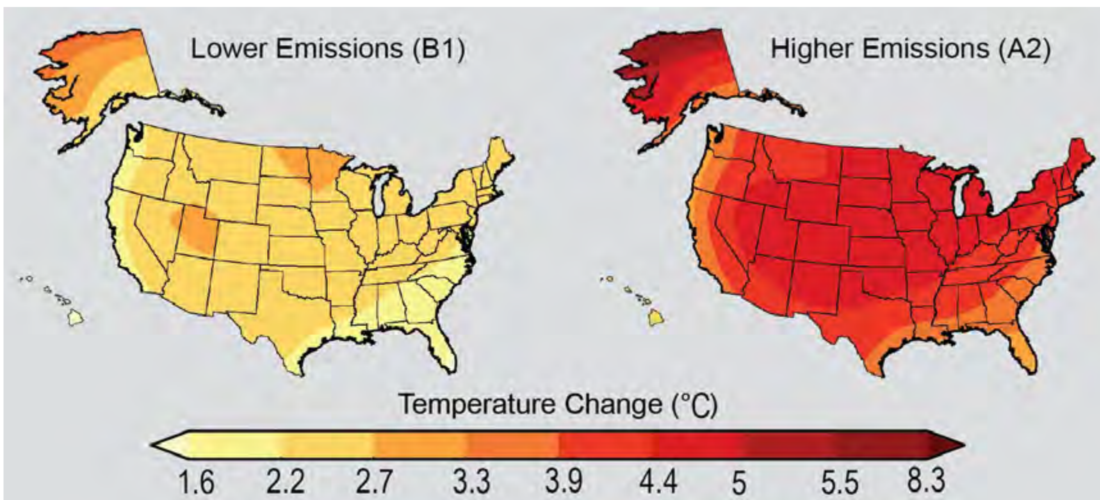


Figure 2.3 Projected temperature change in the USA from 1970-1999 to 2071-2099. Adapted from Walsh et al (2014, 30)

Australia is expected to become hotter, with climatic extremes (drought, temperature, fire weather, heavy rainfall) amplified. Winter and spring rainfall is expected to continue to decrease in southern Australia by up to 15% by 2030, and by up to 20% by 2090 under intermediate emission conditions, and the length of drought projected to increase (CSIRO & the Bureau of Meteorology 2014). Southwestern

Australia has experienced a decline in autumn and winter rainfall since the 1970's, and the southeast since the 1990's (Reisinger et al. 2014). Winter rainfall is projected to decrease further across southern Australia (CSIRO & the Bureau of Meteorology 2014; CSIRO & the Bureau of Meteorology 2015). Increased temperatures, frequency of hot days, and duration of heat waves are all projected to increase across Australia (CSIRO & the Bureau of Meteorology 2014); by 2030, Melbourne, in southeastern Australia, for example, will have up to 40% more days over 35 C, and up to 90% more days over 35 C by 2070 (Reisinger et al. 2014). Figure 2.4 illustrates the mid and upper emissions scenarios for temperatures in Australian, 2070.

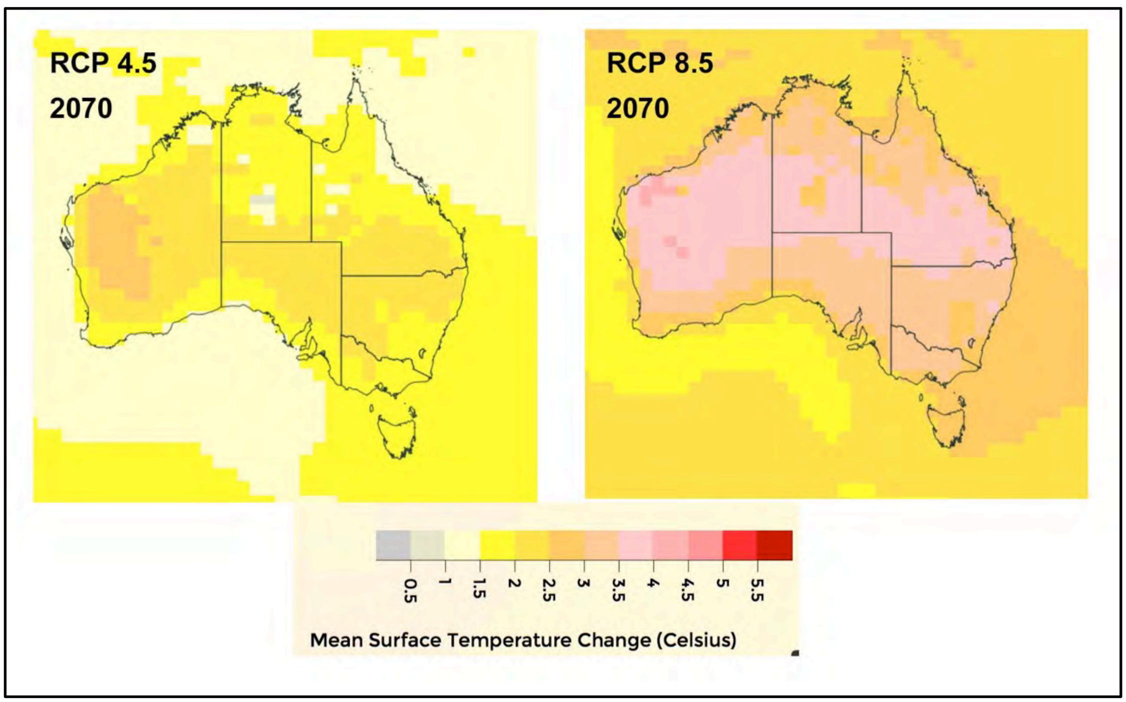


Figure 2.4 Australian climate change scenarios, 2070, lower and upper range. Source: (CSIRO & the Bureau of Meteorology 2014)

Chapter 3

MATERIALS AND METHODS

HYPOTHESIS

This research proposed that Botanic Gardens are more likely to have plans in place to manage water shortage if they have experienced water shortage in the past. Furthermore, gardens located in regions where considerable variation in annual rainfall occur will be more likely to have plans to manage water shortage. Drawing from the experience of these gardens, a range of strategies to manage living collections in the face of water shortage could be then documented.

RESEARCH APPROACH

Australia and the United States botanic gardens are used as the basis for this research because the two countries share similar climatic extremes and issues with water shortage, and they have a long history of public garden institutions. They have an approximately similar landmass; Australia 7.74 million km^2, and contiguous U.S. 8.08 million km^2; and continental, mid-latitude weather patterns. Between them, the USA and Australia offer a broad range of climates and gardens to investigate.

This research adopted the mixed methods approach described by Creswell (Creswell 2009). Two research methods were employed, survey and interview. Quantitative data was gathered to gauge the level of awareness and planning across botanic gardens in Australia and the US with respect to threats to their living collections, including the threat of water shortages. This data collection method was used to determine relationships between types of collections, previous experience with water shortage, and the level of risk management undertaken.

Qualitative data methods were used to examine more deeply the characteristics of botanic gardens that are proactive in assessing the risk of water shortage, and to catalogue and classify the strategies gardens are using to manage the risk of water shortages to their living collections.

Human Subjects in Research

In accordance with University of Delaware policy, and federal law requiring that the Institutional Review Board (IRB) review all research involving human subjects, this research follows the guidelines and procedures and regulations prescribed by the IRB. Human Subjects in Research training was undertaken in Social and Behavioral Conduct of Research, completed 15th March 2015, and Human Subjects Protections – Social-Behavioral-Educational focus, completed 14th March 2015. A copy of the online survey, qualitative research approach and the participants involved in the research was submitted, and the IRB determined that this research was exempt from IRB review on 28 July 2015. The approval letter is attached at Appendix A. Each garden identified in this research has given their informed consent to participate. A copy of each signed consent form is attached at Appendix A.

Quantitative Research

Botanic gardens in Australia and the United States were identified using information supplied by BGCI and BGANZ and BGCI and APGA respectively and a contact list of botanic gardens for each country was compiled from those sources. Gardens on the lists were verified using Google U.S. and Google Australia to search for information about the gardens on the lists as received. If there was no online trace of them, either a website, or reference to them (other than a BGCI listing), the garden was deleted from the list. Gardens that were clearly municipal parks –as evidenced by not matching any of the criteria used by BGCI to qualify as a 'botanic garden' - were also removed. The final list for Australia was 82 gardens, and the United States 605.

An online survey was undertaken seeking information about planning within botanic gardens. The survey sought to determine what kinds of collections were held, whether gardens had a collections policy, the level of general planning for disasters, specific planning for water shortages, the size of the garden, and the amount of water, and type of irrigation currently being used. The survey was constructed using the University of Delaware's Qualtrics online survey tool, and tested and adjusted by graduate students and botanic gardens personnel prior to issue. The survey instrument used Qualtrics' 'display logic' function to display some questions depending on the answer to a previous question.

The survey was emailed from Qualtrics, enabling tracking of the opening and completion rates. Two follow-up reminder emails were sent via Qualtrics to gardens that had not yet responded. Table 3.1 illustrates the sequence of the survey mail outs. The Qualtrics Survey Questions and answers are located at Appendix B. Information has been omitted that identifies individual gardens.

Table 3.1 Qualtrics Survey mail out history and response rate

	Date	Australia	Date	United States
Number of surveys mailed /received by the email recipient	4 Aug 15	82/77	3 Aug 15	605/573
Number of surveys remailed, 2nd Mailout	25 Aug 15	58	27 Aug 15	517
Final follow up email via Qualtrics	13 Sept	13	14 Sept	34
Total Number of surveys opened / received	-	43 / 77	-	112 / 573
Total number of surveys completed / received	-	33 / 77 42%	-	93 / 573 16%

QUALITATIVE RESEARCH

The intention of interviews with individual gardens was to focus on those gardens that are proactive in protecting their collections; discover what motivated them to undertake planning; explore what strategies they were implementing; and what barriers they faced in preparing management plans for water shortage.

Using the responses from the survey, a matrix was constructed to determine which gardens to contact for follow up interviews. A simple scoring system was used to rank gardens according to their responses to planning-based questions in the survey. Each positive response scored '1', and each negative response scored '0'. Given the objects of this research, two questions were given extra weighting to help identify those gardens with water shortage management plans. The response to 'Has a disaster plan' was scored '2' for yes, '0' for no, and the response to 'has a plan to manage water shortage' was scored '3' for yes and '0' for no. All gardens surveyed were then ranked based on the score. Seven gardens from Australia, and five from the United States were shortlisted. Those gardens that did not respond to interview requests were removed from the list. Table 3.2 lists the gardens selected for interview. Based on their high survey scores, several gardens in the United States then participated in screening interviews, however their initiatives were not substantial, and were not further documented. One United States garden was interviewed, and their initiatives documented, but the garden did not return the informed consent form, therefore all identifying information was removed.

Table 3.2 Matrix used to rank gardens according to their responses to planning questions in the survey. The top-scoring gardens were then contacted for follow-up interviews.

	Selection criteria from the survey questions								
	Important Plants flagged in database	Has Disaster Plan	Disaster Plan includes provision for Water	Has a Living Collections Plan	Living Collections Plan has provision for water?	Had Water Shortages previously	Has plan to manage long-term water shortage	Has plan to manage short term water shortage	Total Points
Australian Botanic Gardens									
Albury B.G.	1	2	1	1	1	1	3	1	11
Australian National B.G.	1	2	1	1	1	1	3	1	11
Adelaide B.G.	1	2	0	1	1	1	3	1	10
Melbourne B.G.	1	2	1	1	1	0	3	1	10
R. Tasmanian B.G.	1	2	0	1	1	1	3	0	9
Blue Mount. B.G.	1	2	0	1	0	1	3	0	8
Wollongong B.G.	1	0	0	1	1	1	3	1	8
United States Botanic Gardens									
A south east Garden	1	2	1	1	0	1	3	1	10
U. Cal B.G. at Berkeley	1	2	1	1	0	0	3	1	9
A mid-west garden	0	2	1	1	0	1	3	0	8
A south-west garden	1	2	1	0	0	1	3	0	8
Vizcaya Museum and Gard	1	2	0	1	0	1	3	0	8

A structured interview was held with a senior representative of each case study garden. The interviews ranged in duration from one to 3 hours, and were conducted in person or via phone. A list of questions was used as an interview guide, and interviewees encouraged to digress from the set questions if appropriate. The purpose of the interviews was to discover what prompted gardens to consider water shortages when undertaking living collections planning; understand the challenges involved, and explore the solutions gardens had arrived at. Interviewees reviewed their garden's report and made any final comments and observations.

Survey Analysis

Advice was sought from the University of Delaware's College of Agriculture and Natural Resources Stats Lab to determine the best approach to the quantitative analysis. Quantitative data from the Qualtrics survey was extracted in CSV format and analyzed using JMP statistical package. Survey responses that had not been started, or were started but had no answers recorded were excluded from further analysis. Measures of central tendency, distribution, and chi square tests for independence were undertaken, but owing to the comparatively small number of responses, other analyses were not viable.

Some data was recoded numerically, including the qualitative questions about budget and staff numbers. The number of staff was recoded to group staff numbers in bands of 10 equivalent full time positions. Budget was grouped into four bands of small (<\$500,000) small-medium (<\$5,000,000), medium-large (<\$10,000,000) and large (>\$10,000,000).

Some quantitative data – questions with written responses – were sorted into action categories where possible and appropriate. For example, Question 13 "Please outline how your garden will manage its living collection in the event long-term water restrictions" was coded into four kinds of action themes; collections, horticultural, water and policy. Words suggestive of placement in a particular category are listed in Table 3.3, but some of the placement was about context. The rationale for allocating responses to a particular theme is outlined thus:

- Collections theme: If the action relates to decisions about what species or suite of plants to use.

- Horticulture theme: If the action relates to decisions about what part of the collection to treat, and how it is treated *during* the drought.

- Water theme: If the action is related to upgrading water related infrastructure, or manipulating or measuring the water.

- Policy and External Negotiation theme: If the action relates to negotiating with the water supplier or government authority to achieve policy change.

Table 3.3 Key words from the survey responses used to categorize actions into themes for managing water shortage.

Theme	Words from survey responses
Collections	Thematic, collections, accessions, natives, tolerant, resistant, drought, palette, selection, local, adapted
Horticultural	Mulch, landscape, bed, drought, displays, turf, lawns, trees, rationing, mulch, water, areas, plants, priority, irrigation, shrubs, woody
Irrigation	Water, pipe, potable, restrictions, drinking, irrigation, dam, stormwater, harvesting, aquifer, well, rain, recycle, system, lake, pond
Policy and planning	Planning, drought, restrictions, government, authority, relationship, strategic, management, meetings

Each garden's individual response was separated into single actions, and each single action was categorized. For example, one United States garden's response was separated into two actions:

> We are planting more native, drought tolerant plants (collections theme) AND
>
> We are looking at drilling a well, which is not restricted (water theme)

Similar actions proposed from different gardens were then grouped together into one strategy, for example, “most turf areas are allowed to go dormant”, “lawn reduction”, “we have let the ‘great lawn’ die” and “turf areas have been identified as potential areas for further reductions or shut down if water availability is further reduced” were all statements about reducing or eliminating turf watering and were accordingly placed into the category ‘reduce or eliminate turf watering’. The full table of individual garden’s actions to manage long-term water shortage is at Appendix C, Appendix Tables C.1 and C.2. For clarity, the groups of actions were then consolidated in a new table under each of the four major themes (shown in Table C.3, Appendix C)

Questions about challenges involved in developing a plan to manage long-term water shortage, (Q14); barriers to developing such a plan (Q15); and how short-term water shortage will be managed (Q17) were treated in a similar manner, with individual elements itemized, as per Tables C.4 –C.9, Appendix C.

Location of Gardens

United States gardens were grouped by state, and then those states sorted into climate regions defined by the National Centers for Environmental Information (NOAA 2016). Nine such climate regions are located in the contiguous 48 states. The resulting groups of climate regions were then compared against survey variables to determine any relationship. There were insufficient Australian gardens to sort into climatic regions.

Chapter 4

SURVEY RESULTS

LOCATION OF SURVEYED GARDENS

Ninety-two United States gardens completed the survey and seventy provided the garden's name. Thirty-seven Australian gardens completed the survey, and thirty-two provided the garden's name. Identification of the garden's name and address was optional; some gardens provided just their state location, while others provided full details. Figure 4.1 shows the United States locations and Figure 4.2 the Australian locations of those gardens.

Figure 4.1 Geographical location of the 70 United States gardens that self-reported in the survey

Figure 4.2 Geographical location of the 32 Australian gardens that self-reported in the survey

Seventy United States gardens provided the address of their garden, and a further three gave their state location. Survey respondents were from 29 states, including Hawaii; Figure 4.3 shows the number of gardens from each state.

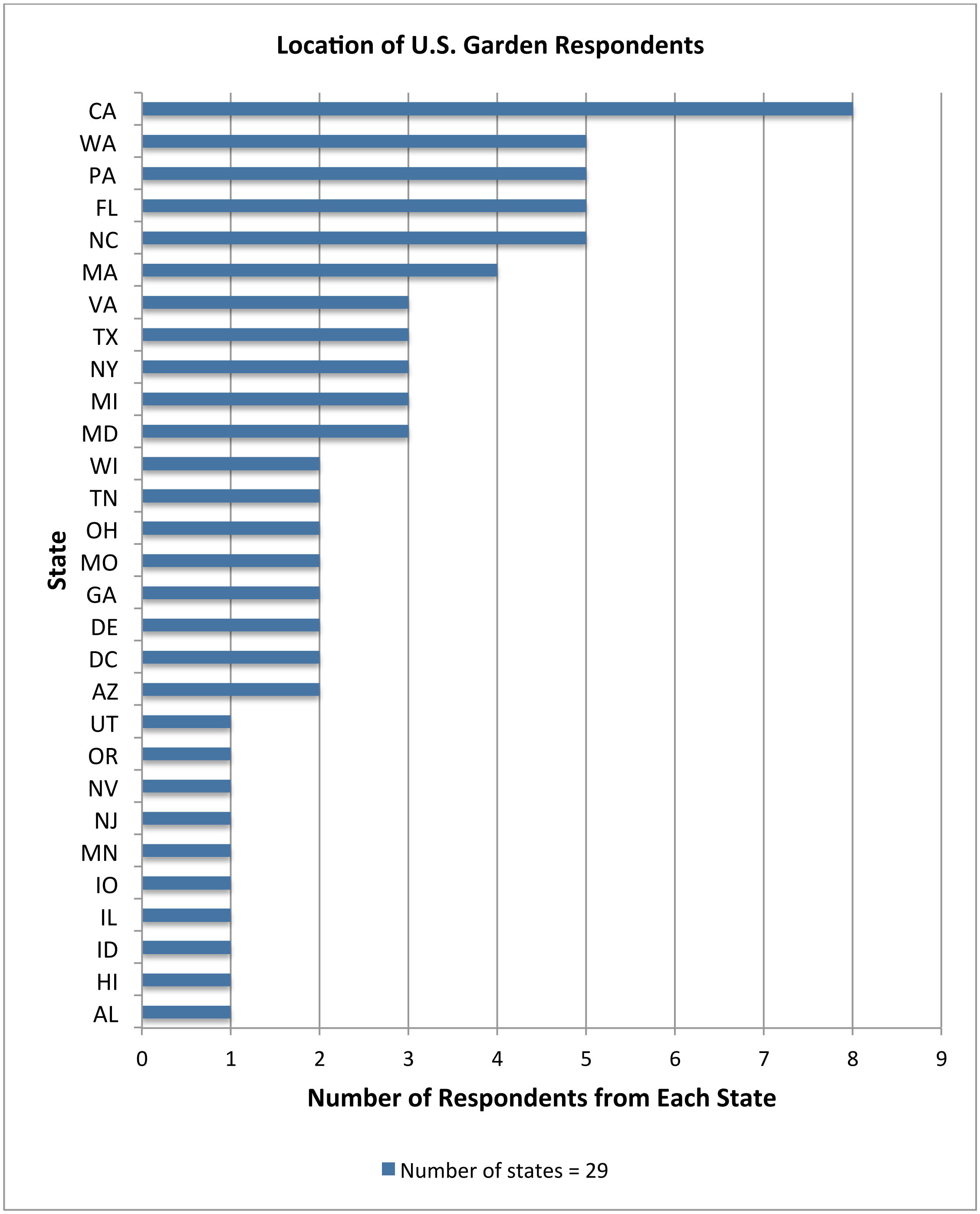


Figure 4.3 Location of United States survey respondent gardens by State

Living Collection Information

Questions sought census information about the botanic garden's living collection, including the number of living accessions, as shown in Table 4.1. Some gardens did not have their plants recorded on a database. More than half of the gardens in both countries had fewer than 5,000 living plant accessions, with most (94%) having fewer than 20,000.

Table 4.1 Census information relating to survey respondent gardens' living collection

Living Collection Census Information	U.S. n	Aust n
The number of living accessions recorded in the garden's plant database		
Number of responses	77	20
Minimum number of accessions	150	220
Maximum number of accessions	47183	48840
Median number of accessions	4500	4000
Mean number of accessions	6585	6863
Do not know, and do not have a plant database	4	4

Information was sought about specific categories of living collections that may be important to botanic gardens, depending on their collections focus. Plants grown from the original living plant from which the 'type specimen' was collected are often considered a significant part of living collections. Documented wild-collected plants, documented wild-collected IUCN Red-Listed plants, and in many cases (but not always) plants having collecting restrictions, are central to gardens with plant conservation objectives; these groups of plants are considered 'conservation' kinds of collections in terms of the Global Strategy for Plant Conservation (GSPC) in this analysis. Plants can be difficult to re-acquire for various reasons, for example, they may be extinct or very rare in the wild; the Convention on Biodiversity restrictions may preclude recollecting; or quarantine regulations may prohibit importation. Plants can be expensive to replace for a number of reasons; for instance, recollecting from the wild will often have significant associated costs, and the cost of purchasing and delivering replacement display plants may also be a significant expense. Figure 4.4 illustrates the percentage of gardens holding each specified category of collection. The larger percentage of gardens in Australia who state their collections would be ‘difficult to reacquire’ is likely due in some part to Australia’s plant quarantine regulations now prohibiting the import of formerly permissible plants.

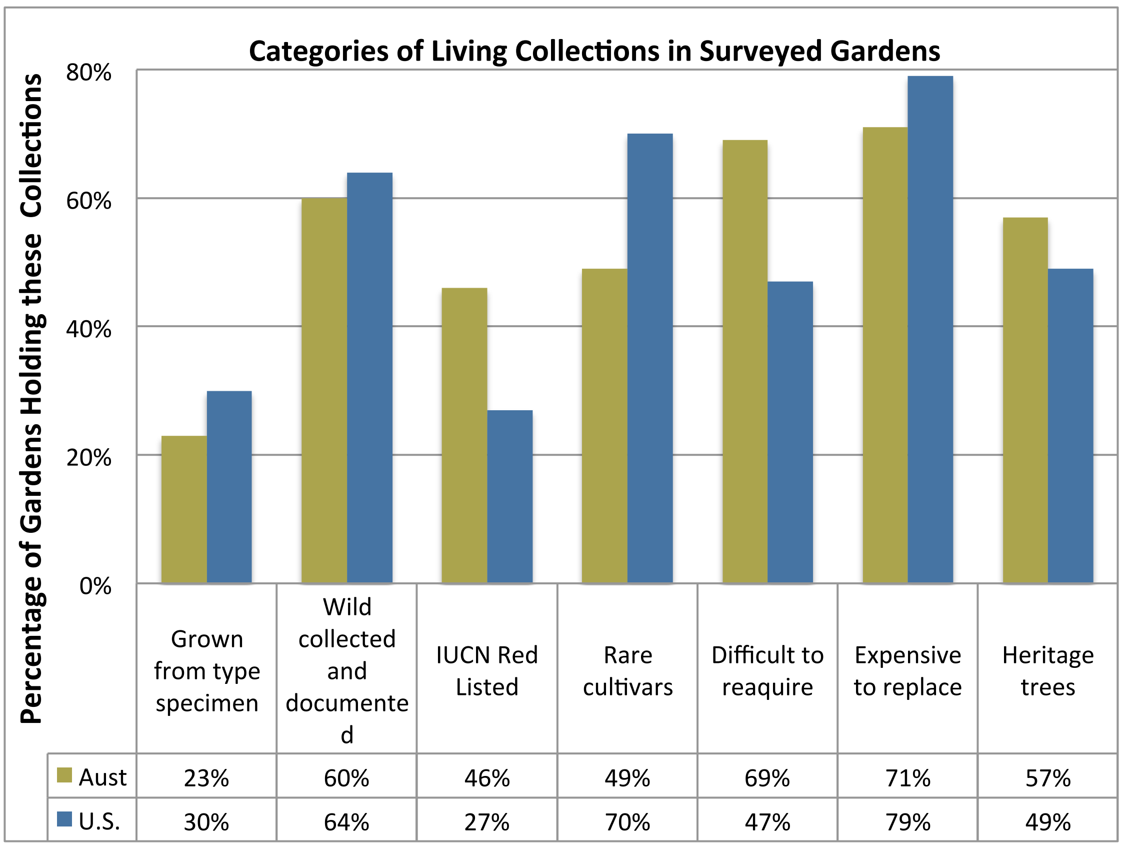


Figure 4.4 Percentage of all respondent gardens growing each different category of living collection

Planning for Disasters, Water Shortage and Collections Planning

The survey collected data on whether the garden had planning or management documents for the living collection, including a living collection policy or plan; a disaster management plan; whether the disaster plan included water shortage; if the important plants in the collection were identified and listed separately; and if the living collections plan had changed in response to water shortage, as shown in Figure 4.5.

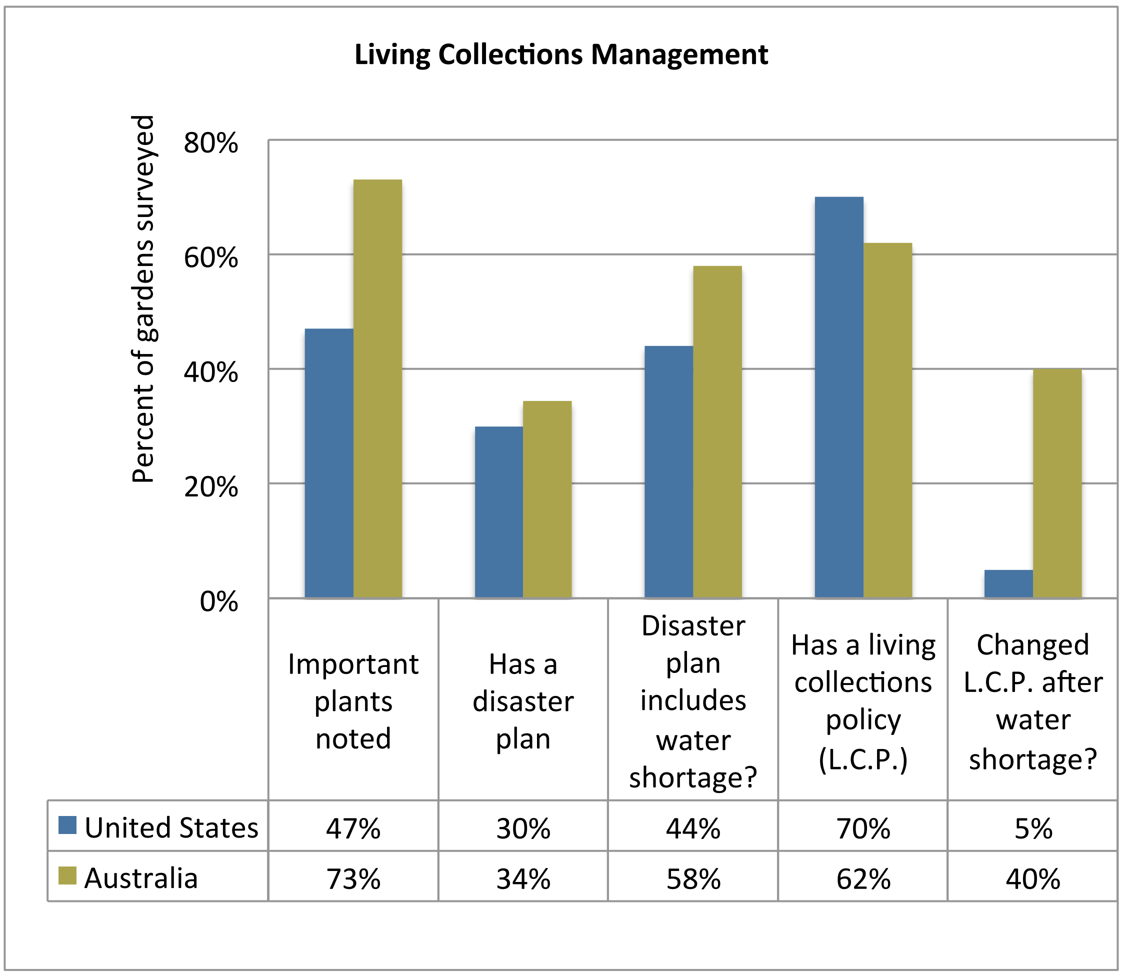


Figure 4.5 Percentage of gardens in United States and Australia with policies and procedures related to living collections management.

Ten Australian gardens, 42% of the gardens with a living collections policy, had changed their policy in response to drought or water shortage. Nine of these 10 gardens indicated that matching plants to the climate was a priority in new plantings; the tenth garden has categorized its existing collection based on the level of importance of the components, and whether it could be sacrificed in the event of water shortage. Changes to the living collection included:

> The incorporation of sourcing species that are climate compatible within all collections policies (Australia)
>
> Through plant selection, integrated water management, creation of a Strategic Water Plan, development of a Landscape Succession Strategy that takes into account climate projections of 2090 (Australia)
>
> In regards to the future development of living collections we have made it policy to consider collections that will be suited to a drier climate with less rainfall and requiring less frequent irrigating. Essentially, collections that are more suited to our climate. (Australia)

Few gardens in the United States had changed their living collection policies due to water shortage, however three gardens with a living collections policy indicated they had changed in response to drought or water shortage.

> Increased focus on Mexican collections and rare natives. (United States)
>
> Accepting no new accessions until drought is over, unless plants are water wise and need watering rarely or occasionally (United States)
>
> We have a limit on the number of new installations that can be put in during a single year to manage the watering needs in the following years. An unwritten policy has been to move many of the display garden areas from annuals to perennials and grasses to reduce the water demand. (United States)

Using chi-square test of independence, living collection plan or a disaster plan was compared against all collections categories, to determine any relationship. Disaster plan, living collection plan and whether the garden had its important plants listed separately were also compared. The premise is that 'conservation' categories of collections would be associated with having a living collection plan and a disaster plan, and are also associated with having important collections flagged in the database. Where a relationship was evident it is listed in Table 4.2.

Table 4.2 Chi Square test of Independence: Pearson's Test Significant relationships between planning documents and kinds of collections held

Variable x	Variable y	Relationship: Prob > ChiSq
Australia		
Living Collections Plan	Wild Collected Plants	$X^2(1, N = 34) = 4.84, p = 0.0278$*
Disaster Plan	Living Collections Plan	$X^2(1, N = 33) = 12.26, p = 0.0005$*
Disaster Plan	Wild Collected Plants	$X^2(1, N = 35) = 4.14, p = 0.0418$*
Disaster Plan	Expensive to replace plants	$X^2(1, N = 35) = 6.32, p = 0.0119$*
Disaster Plan	Important plant flagged in the data base or listed	$X^2(1, N = 35) = 5.41, p = 0.0200$*
Expensive to replace plants	Important plants flagged in the data base or listed	$X^2(1, N = 35) = 7.35, p = 0.0067$*
United States		
Living Collections Plan	Wild Collected Plants	$X^2(1, N = 88) = 26.23, p = 0.0001$*
Living Collections Plan	IUCN Red Listed Plants	$X^2(1, N = 88) = 9.50, p = 0.0021$*
Living Collections Plan	Plants with restrictions on recollecting or reacquiring	$X^2(1, N = 88) = 14.44, p < 0.0001$*
Disaster Plan	Plants grown from the Type Specimen	$X^2(1, N=90) = 6.96, p=0.0083$*
Disaster Plan	Plants with restrictions on recollecting or reacquiring	$X^2(1, N = 90) = 4.71, p = 0.0299$*
Disaster Plan	Important plants flagged in the data base or listed	$X^2(1, N = 90) = 21.63, p<0.0001$*

Having a disaster plan was compared with having a plan to manage water shortage. The hypothesis is that these two plans demonstrate that the garden practices some level of risk management, and if a garden has a plan to manage water shortage there will be a relationship to having a disaster plan. Having a plan to manage water shortage was then compared with experiencing water shortage in the past. The hypothesis is that if a garden has already experienced water shortage, there will be a relationship to having a plan to manage it. Where a relationship was evident it is listed in Table 4.3.

Table 4.3 Chi Square test of Independence: Significant relationship between having a plan to manage water shortage and previous experience with water shortage

Pearson's Test of a relationship between two variables.	
	Relationship: Prob>ChiSq
Australia Has a plan to manage water shortage and:	
Has a Disaster Plan	$X^2(1, N = 32) = 6.97, p = 0.0083$*
Had water shortage **once, or more than once**	$X^2(2, N = 33) = 6.31, p = 0.0426$*
Had water shortage **at least once**	$X^2(1, N = 33) = 6.31, p = 0.0120$*
Has heritage trees	$X^2(1, N = 33) = 4.89, p = 0.0270$*
Knows how much water is used	$X^2(1, N = 30) = 6.11, p = 0.0134$*
Has plan to manage short-term (emergency) shortage	$X^2(1, N = 32) = 9.41, p = 0.0022$*
United States Has a plan to manage water shortage and:	
Has a Disaster Plan	$X^2(1, N = 86) = 5.36, p = 0.0240$*
Had water shortage **once, or more than once**	$X^2(2, N = 87) = 21.06, p <0.0001$*
Had water shortage **at least once**	$X^2(1, N = 87) = 18.54, p < 0.0001$*
Has rare cultivars	$X^2(1, N = 88) = 7.67, p = 0.0056$*

Gardens were asked if any important living collections had been lost due to water shortage. Material lost varied, but respondents commented on the loss of mature trees and heritage trees, and the loss of trees in areas that were not irrigated. Nine Australian gardens lost mature trees, heritage trees, and species primarily from Australian tropical and subtropical rainforest habitats. Twenty-four U.S. gardens reported losing collections, including many trees, in particular oaks, pines, elms, spruce, *Sequoia* and *Sequoiadendron*. Newly established trees were vulnerable, with seven gardens reporting the loss of new plantings and young trees. The full response can be found at Q7, Qualtrics Survey results, Appendix B, and is summarized at Figure 4.6.

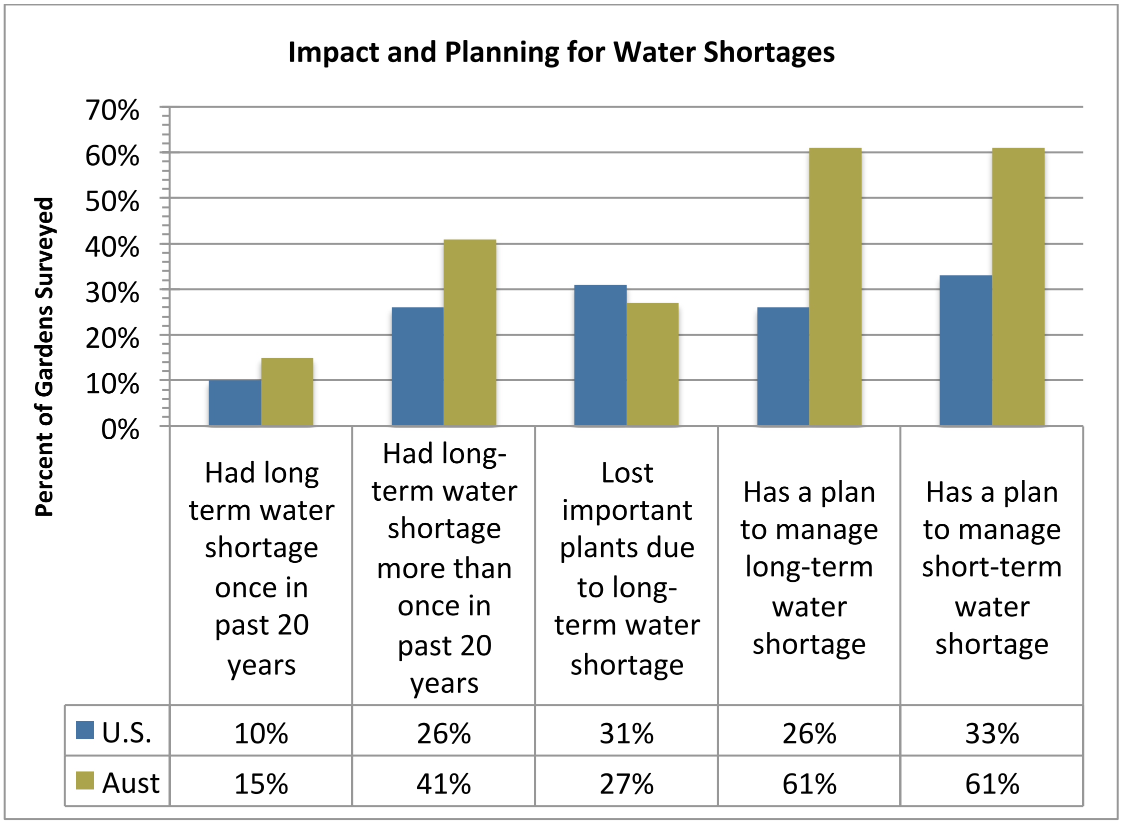


Figure 4.6 Australian and U.S. gardens reported experience of water shortage

Strategies that gardens have, or will adopt to manage short-term water shortage are summarized in Figure 4.7. Each action was assigned to a category, tabulated, per Tables C.8 and C.9, Appendix C. Most of the strategies are based on using an alternative, temporary source of water, with two gardens relying on their plants being sufficiently drought tolerant.

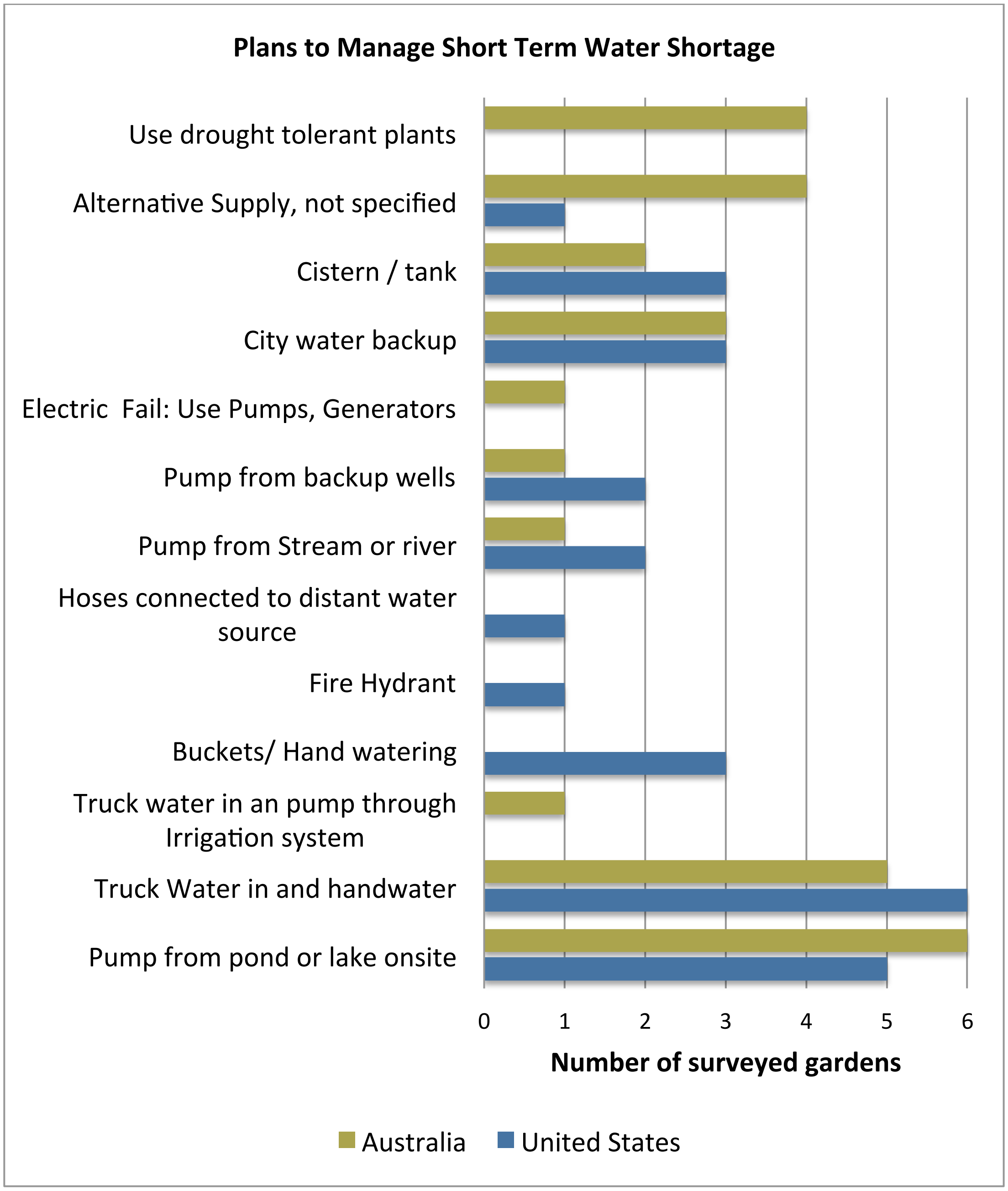


Figure 4.7 Reported strategies gardens will employ to manage short-term water shortage.

Plans and Strategies to Manage Long-term Water Shortages

As noted, there was a relationship between experiencing past water shortages and having a plan to manage this. Twenty Australian gardens (61%) had a plan to manage long-term water shortages, and 23 U.S. gardens (26%) had a plan. Figure 4.8 illustrates the relationship between frequency of water shortage and having a plan to manage this.

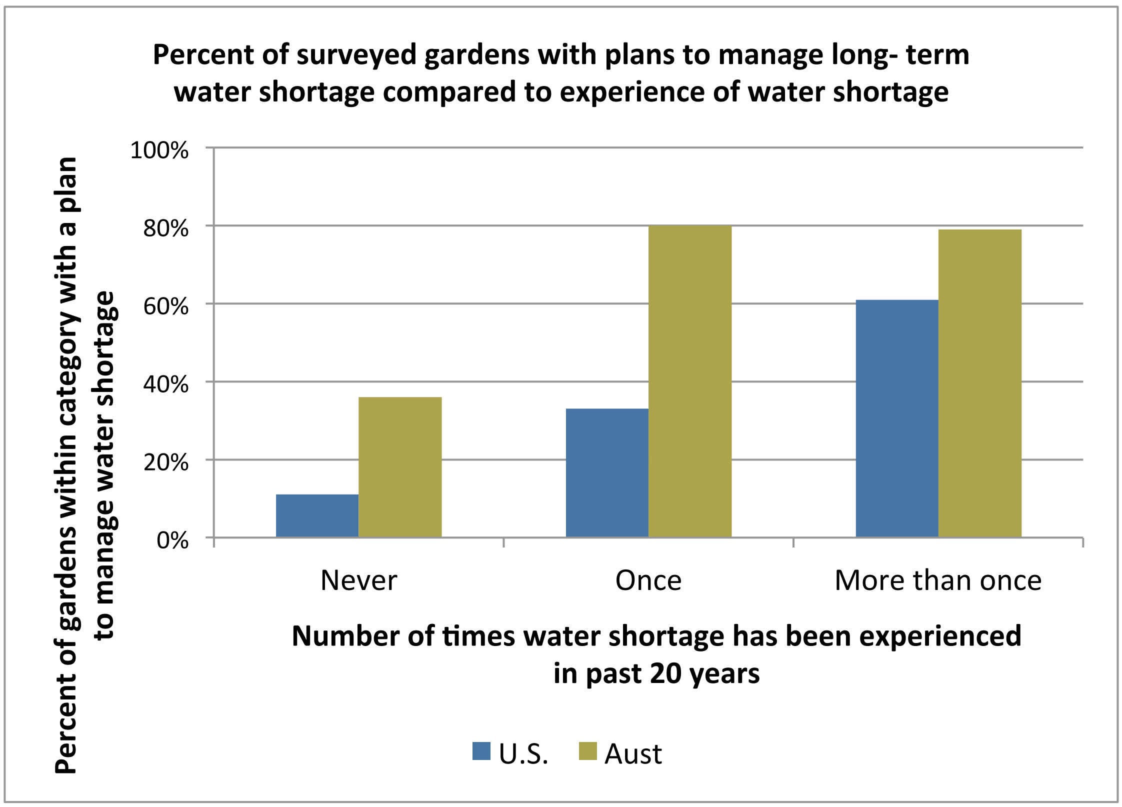


Figure 4.8 The connection between the frequency of water shortage and having a plan to manage this.

If the garden indicated they had a plan, they were then asked to describe how the garden would manage its living collection in the event of long-term water restrictions. Most gardens proposed several actions as part of their plan. Twenty different strategies were identified and tabulated in this manner as Figure 4.9 illustrates. The full set of responses and thematic coding to this question (Q13) is in Appendix C Tables C.1 to C.3. Sample strategies include:

> We have our own water source and our long-term plan is to limit irrigation to water from our own source, rather than using purchased water. To do this, we need to build more storage capacity, to maximize our water collection, increase stormwater infiltration, and improve efficiency of irrigation. (United States)

> We manually irrigate select garden plants in order of priority: / Trees (that aren't drought tolerant) / Other woody plants i.e. shrubs and vines (that aren't drought tolerant) / Misc plants that would be extremely difficult to replace / T&E plants particularly if not waterwise / We would accept the loss of herbaceous material, unless it rare or extremely difficult to replace. (United States)

> Still in the planning process to expand the reclaimed water use on the property. This source of water is not restricted in a drought. (United States)

> We have identified 'sacrificial collections' to ensure water is used on our most important collections. Sacrificial collections are display beds, and collections that can be readily replaced. (United States)

> Current garden bed water management is at a minimum application rate allowing the plants to adapt to restrictions. Turf areas are ranked according to priority for water use. Turf areas have been identified as potential areas for further reductions or shut down if water availability is further reduced. (Australia)

> We are in the process of installing a system to recycle grey water (sewerage) back into the water thirsty turf. This will reduce the draw on our only dam. Our Strategic Planning Framework highlights the need for an additional dam to be installed to cover the site's needs into the future. (Australia)

> Water trucks, change plant palette to plants which don't need irrigation (Australia)

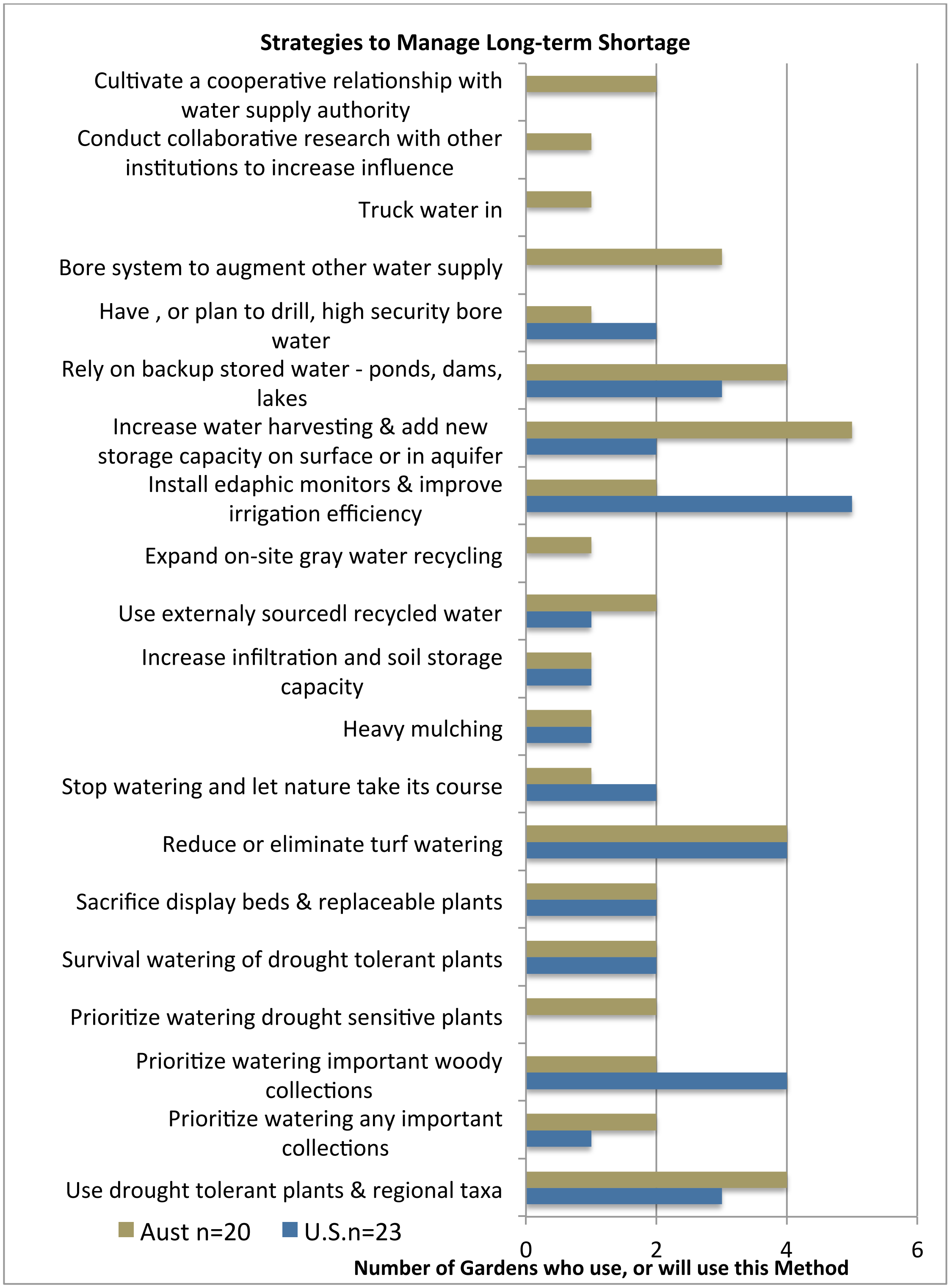
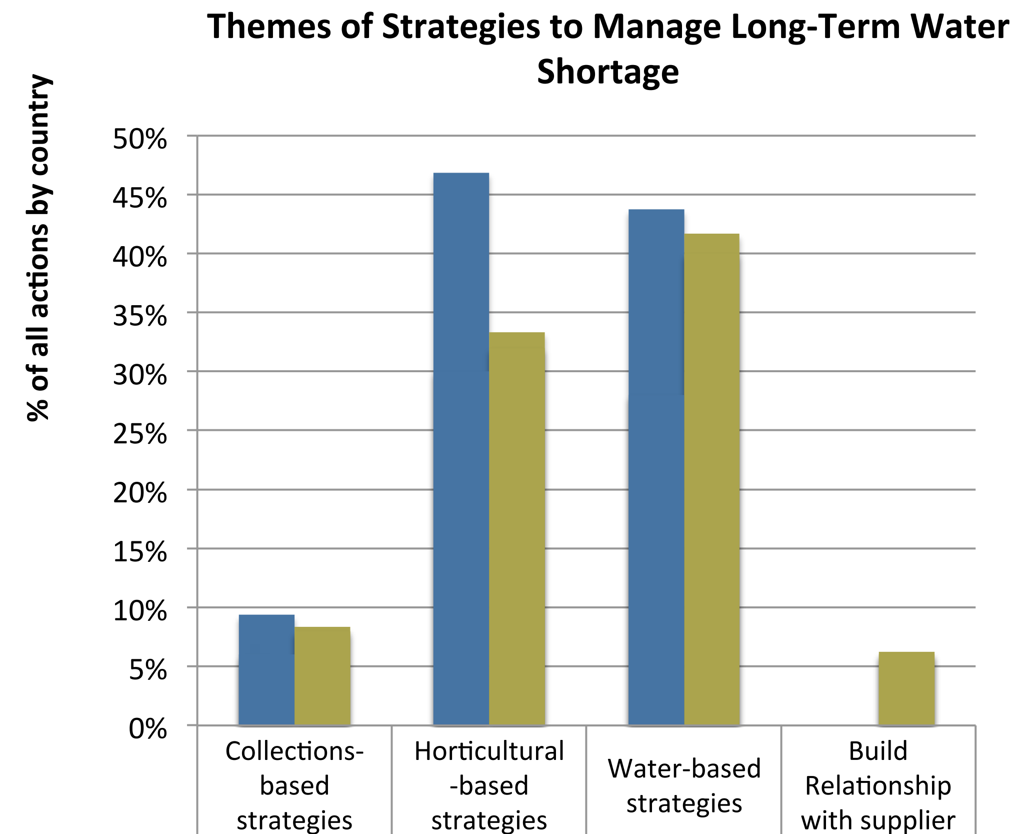


Figure 4.9 Actions to manage long-term water shortage sorted by action group

The twenty strategies were further assigned to four major thematic categories, grouped into horticultural focus, collections focus, water focus and building relationship with water supplier, and summarized in Figure 4.10. The coding chart is shown at Appendix C Table C.3.



	Collections-based strategies	Horticultural -based strategies	Water-based strategies	Build Relationship with supplier
U.S. %	9%	47%	44%	0%
Aust %	8%	33%	42%	6%
U.S. number	3	15	14	0
Aust number	4	16	20	3

Figure 4.10 Strategies to manage long-term water shortage coded by theme.

Gardens reporting they have a plan to manage longer-term water shortages were asked if there were any challenges in developing and implementing the plan. Eighteen gardens from each of the United States and Australia responded to this question, their responses were broken down into individual items, as summarized in Figure 4.11. The full list of responses and coding is in Appendix C Tables C.4 and C.5. Examples of challenges were:

> Comprehensive consultation process and bore water table levels are diminishing progressively. (Australia)
>
> If the water shortage is the result of an earthquake, and subsequently major waterlines, we may not have access to water to implement the plan. (United States)
>
> Plenty, funding, construction, operation. Having dedicated staff in this area is a must. (Australia)
>
> Keeping our plan consistent with other (city and state developed) drought response plans. (United States)
>
> The most critical challenge is the relationship between the trees living in turf areas and working out how best to manage the trees to adapt to less water. / We have adopted a transitional reduction in many turf areas to try to drought proof the trees should additional water restrictions be imposed. (Australia)
>
> Yes, objection to lawn replacement and loss of functionality of lawn areas. (United States)

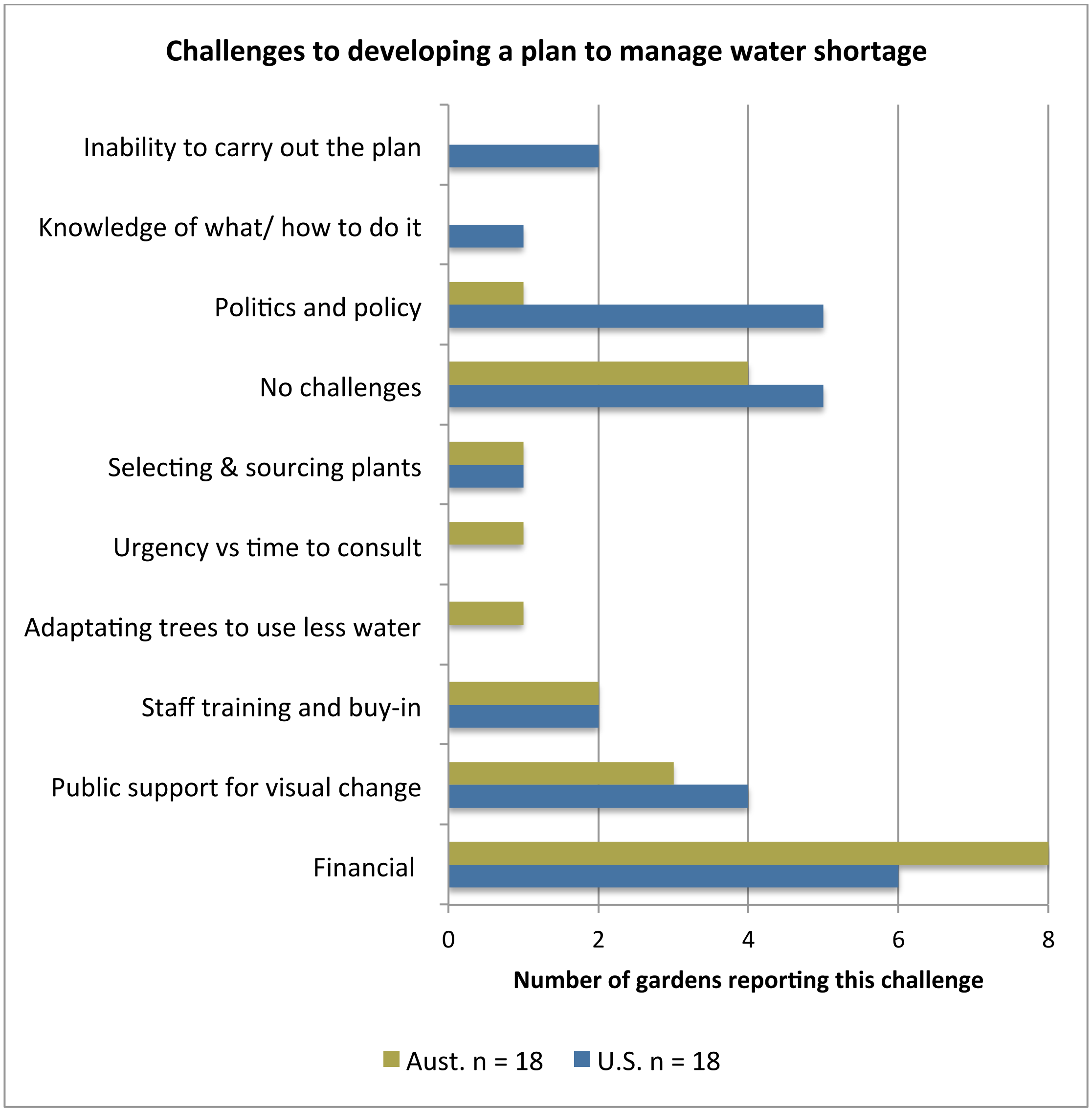


Figure 4.11 Challenges experienced by gardens when developing a plan to manage water shortage.

Gardens that did not have a plan to manage longer-term water shortage were then asked to list any barriers to developing one. Forty-eight U.S. and eight Australian gardens responded with comments, summarized in Figure 4.12. Some gardens provided more than one constraint, and each one was separately listed and categorized. The full list of barriers is provided at Appendix C, Tables C.6 and C.7.

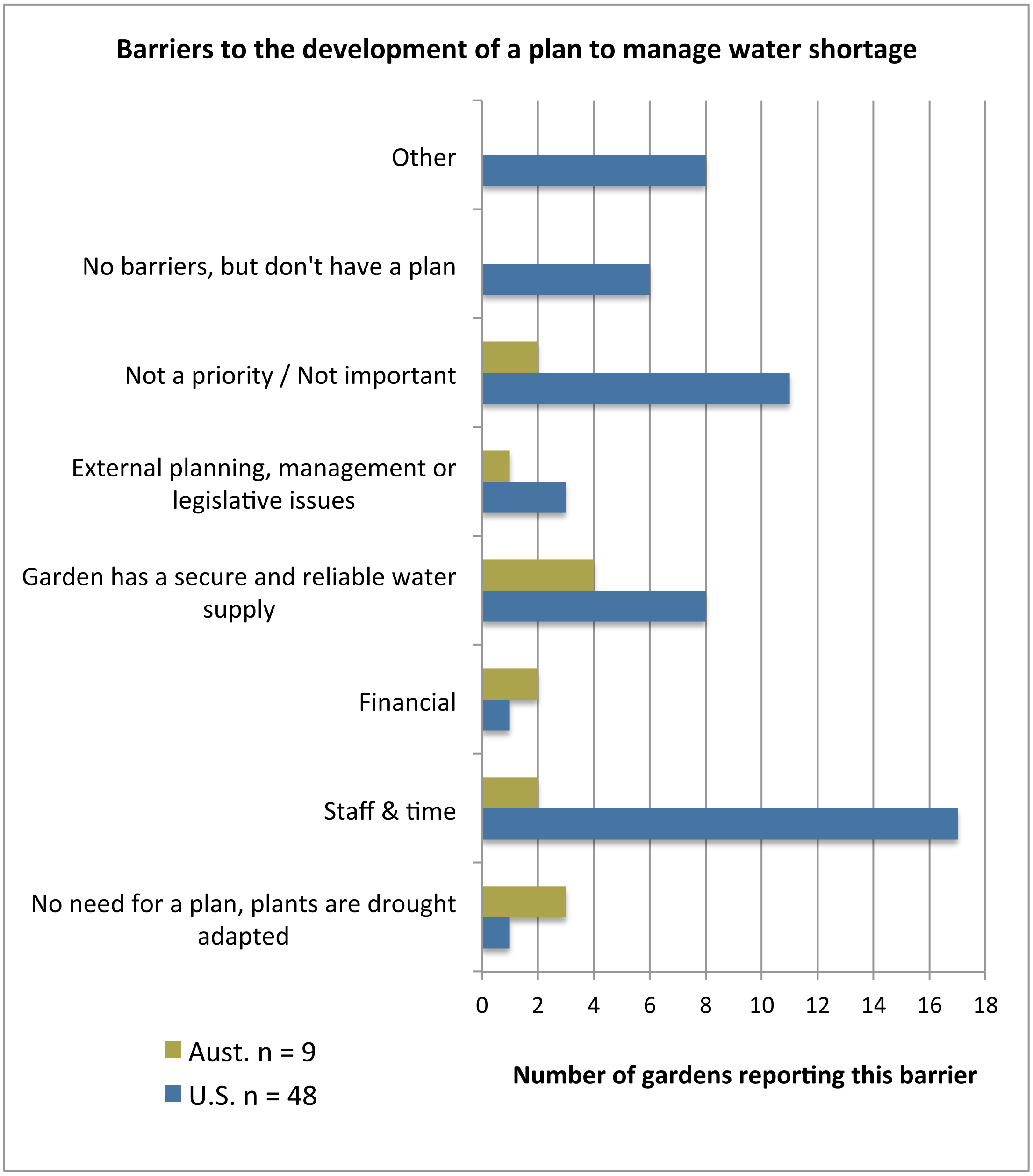


Figure 4.12 Barriers to developing a plan to manage long-term water shortage reported by respondent gardens. Each individual reason was tabulated.

Survey respondents were invited to provide additional comments regarding their preparedness for water shortage. Fifty-two United States gardens and twenty-three Australian gardens provided observations, comments and further information. The full list is located in Appendix B, Qualtrics Survey Results. Some sample comments:

> Long term we are changing beds to capture and store as much water in the soil as possible. (Australia)
>
> Transition the palette of plants so they become less reliant on irrigation and are more resilient to the future climate. (Australia)
>
> It is an issue that remains a priority during and in between water restrictions and availability. Our focus is to deliver the most effective and efficient method of water delivery to our diverse living collection containing over 6000 taxa but ensuring we do so without losing valuable plants from the collection. (Australia)
>
> Thanks for giving us something else to worry about! This is not a topic we've given much thought, but it is something we should be addressing (United States)
>
> We have drastically reduced water use with automation of our irrigation systems. (United States)
>
> Future planning for new areas includes detailed research into care requirements, water needs, plant adaptability, and   companion planning. Current garden zones are intensive maintenance and require careful use of companion planting, watering, and maintenance. (United States)
>
> Our public garden has need of a botanical collections management plan-time and resources have not been prioritized to the development of such and we acknowledge the lack of such a comprehensive plan of action to encompass the preservation and conservation of our plants. (United States)
>
> This is a big strategic issue - right at the heart of what we all do. Thanks for taking it on. (United States)

Location of Gardens with Plans to Manage Water Shortage

U.S. States were coded into the nine climate regions of NOAA's classification in the contiguous 48 U.S. states (NOAA 2016) as shown in Figure 4.13, and the number of gardens stating they had a plan to manage water shortage indicated for each region. A contingency analysis of 'plan to manage water shortage' (y/n) was done for gardens in each climate region, however there was insufficient data to determine any significance. A higher percentage of United States gardens in the south and west have water shortage plans than those in the east and north. The Hawaiian garden was not included in this exercise, as it did not have a water shortage plan. An insufficient number of Australian precluded grouping them together by climate region for analysis.

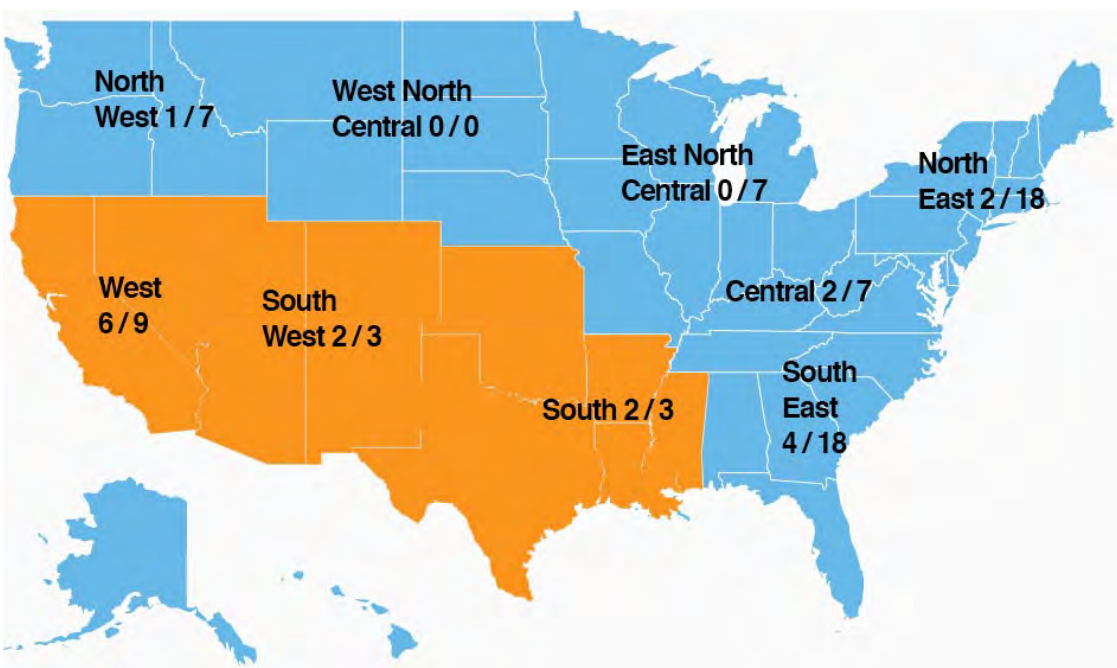


Figure 4.13 United States Climate Regions showing the number of gardens in each region with a plan to manage water shortage, compared with the total number of gardens in each region. Map modified from NOAA (2016)

Irrigation Water

Gardens were asked how much water they use daily in irrigation. Of the Eighty-four U.S. gardens that responded, six provided daily use figures. Fifteen Australian gardens provided daily, seasonal or yearly figures. The water use figures are available in Appendix B, Question 20 and 21 of the Qualtrics survey for each country. There was insufficient data from either country to draw any conclusions about water use, other than precise daily water use figures were not known for most gardens in either country.

The source of irrigation water for both Australia and the U.S. varies. In the U.S. more than half of the gardens surveyed rely on municipal water (55%), in Australia municipal water is the main irrigation water source for 31% of gardens. Some gardens have alternative sources in the event the main supply is interrupted. Figure 4.14 illustrates the different water sources. Chi square contingency analysis showed no significant relationship between water shortages and water source for either Australia or the United States.

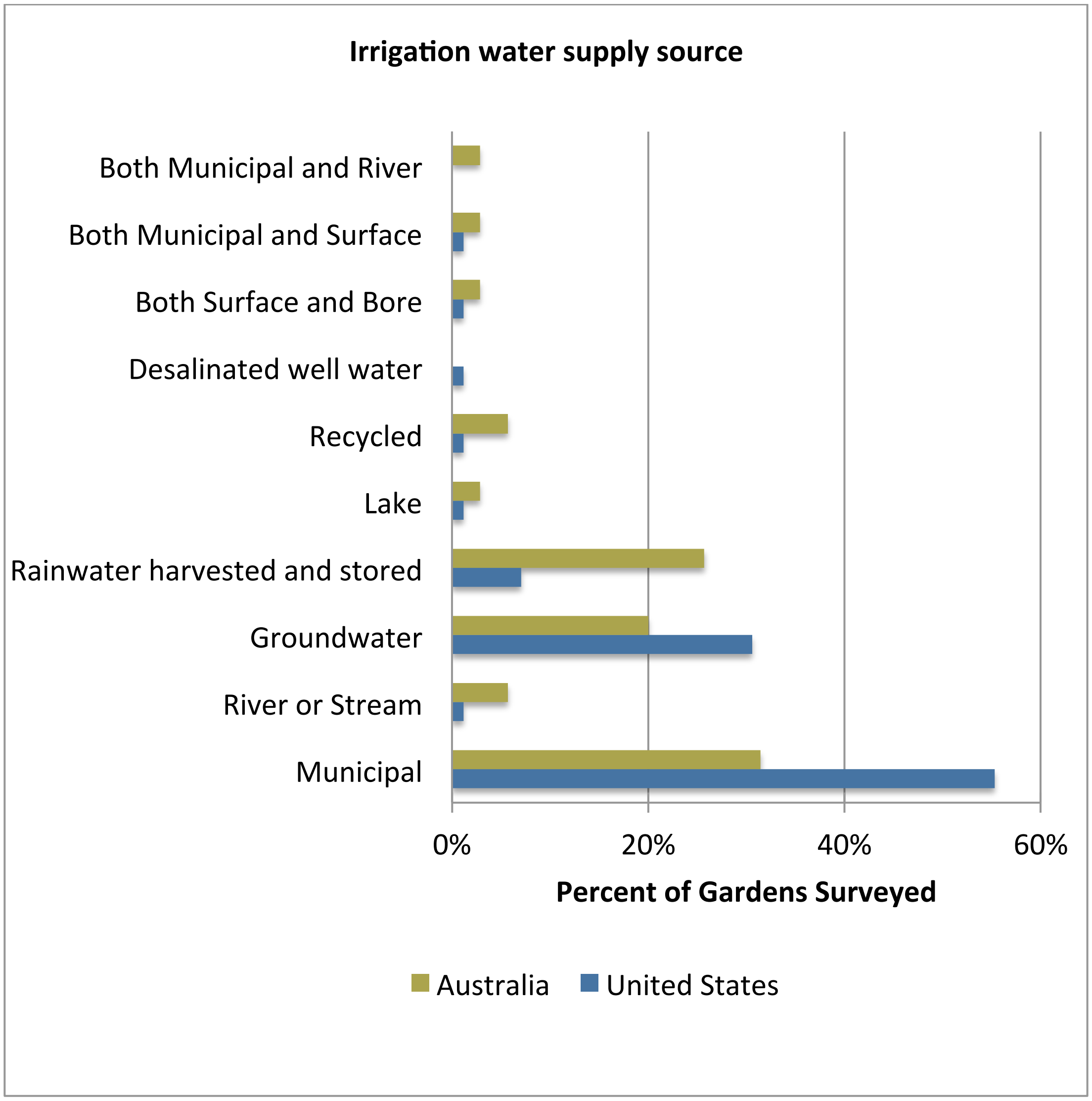


Figure 4.14 Irrigation water source of surveyed gardens.

Chapter 5

CASE STUDY INTERVIEWS

This chapter presents the information and observations garnered from interviews held with individual gardens in Australia and the United States. The date of interview, and name and position of interviewees is listed at the beginning of each section. A description of the garden and its collections, the context of its location and climate, and previous experience with managing water shortages is provided for each garden. Planning initiatives for managing collections in the face of water shortage are then categorized under:

- Horticultural and operational management
- Adaptations to living collections
- Water delivery and infrastructure improvements
- Increasing water storage capacity
- Water supply policy and water pricing initiatives
- Other factors

The challenges and experience of planning for, and managing water shortage, and subsequent insights and recommendations made by the interviewees, concludes each garden's narrative.

Australian garden interview subjects refer to levels of water restrictions, which were imposed in most Australian capital cities during the Millennium drought. Higher levels mandated less allowable water uses. Depending on the city, level one water restrictions typically prohibited washing down hard surfaces such as driveways and sidewalks, and also limited the time during which gardens could be watered. The limitations imposed were progressively more severe through the levels, up to level five restrictions, which prohibited all outdoor use, including all garden watering.

THE AUSTRALIAN NATIONAL BOTANIC GARDEN CANBERRA AUSTRALIA

The Australian National Botanic Gardens' Curator David Taylor and Lucy Sutherland, National Coordinator of the Australian Seedbank Partnership were interviewed by phone on January 16th 2016. A preliminary in-person interview was also held with David Taylor on October 27th 2015 in Wollongong, Australia.

The Australian National Botanic Garden (ANBG) is located in Canberra, Australian Capital Territory (ACT). The Garden was initiated in 1949 and officially opened in 1970, deriving the majority of its funding from the Australian Commonwealth Government. The ANBG holds the world's largest living collection of documented and vouchered Australian plants, about 28% of known Australian flowering plant species, 6,000 taxa and 15,000 wild collected accessions. Of the ANBG's 40 hectares, 20 hectares are developed, with the upper reaches preserving the remnant dry *Eucalyptus* woodland, its location on the lower elevation of Black Mountain provides a range of topography and microclimates. The ANBG is internationally significant for its living plant collections, including rare and endangered Australian plants; its herbarium collection, including more than 8,000 type specimens; and its horticultural, taxonomic and ecological research into Australian plants (Director of National Parks 2012).

Canberra, situated 120 km (74 mi) inland from the coast, has a continental climate with cool winters and warm to hot summers. Table 5.1 details the climate averages for Canberra. Potable water for the City of Canberra is sourced from a series of storage dams on the Cotter River. Lake Burley Griffin, the large artificial water body in the city of Canberra, is supplied from a separate source, the Molonglo River, both rivers ultimately flow into the Murrumbidgee River then the Murray/Darling system. The city, like many parts of Australia, experienced the Millennium Drought, the multi-year deficit in rainfall that impacted much of Southern Australia in the first decade of the 21^{st} century.

> I honestly can't remember which was the worst year of the drought, which persisted over more than seven years. There were several periods that we were really getting close to going to level two water restrictions… we investigated things like trucking water and reviewing what other institutions had done during times of water crises at the time (David Taylor).

Table 5.1 Climate averages for Canberra, Australian Capital Territory. (Australian Bureau of Meteorology 2016b)

Climate Averages - Australian National Botanic Gardens Canberra		
Average maximum summer temperature	27.7^0 C	81.8^0 F
Average minimum summer temperature	13.0^0 C	55.4^0 F
Highest recorded temperature	42.2^0 C	108^0 F
Average days per year > 30 deg C / 86 deg F	10 days	
Average days per year > 35 deg C / 95 deg F	2 days	
Average maximum winter temperature	11.2^0 C	52.2^0 F
Average minimum winter temperature	-0.2^0 C	31.6^0 F
Lowest recorded temperature	-10 C	14^0 F
Average annual rainfall mm / inches	629 mm	24.8 Inches

The size of the city's water storage was increased after the city was placed on severe water restrictions between 2006 and 2010, although 'permanent' water restrictions are now in place prohibiting a range of water use activities, including the use of sprinklers or irrigation systems in public parks and gardens between 9am and 6pm without a permit.

The major natural disaster concern, other than drought, is bushfire. In 2003, lightening strikes started a bushfire that eventually killed four people, destroyed more than 500 homes, and burnt out most of the pine forests and national parks in the Australian Capital Territory, including the city's water catchment, some 164,000 hectares (405,000 acres) in total. The bushfire burned to within a few hundred meters (yards) of the ANBG and the *Eucalyptus* woodland of Black Mountain.

In response to the ongoing drought, and the possibility of Stage 4 water restrictions being imposed (which would have permitted only non-potable water to be used), in 2007 the ANBG finalized a water management strategy to ensure the survival of its living collection, implementation of which is ongoing. The strategy had eight aims (Verrier 2009:30):

1. Separate potable water supply for buildings
2. Secure non-potable supply for irrigation
3. Establish an ANBG irrigation improvement program
4. Review living collection species selection
5. Modify landscaping within the ANBG to ensure maximum water efficiency and effectiveness of irrigation
6. Build staff capacity in irrigation management
7. Increase community awareness
8. Develop a research program to inform non-potable water, drought and CO2 tolerance of native plants as they relate to climate change.

Planning Elements

Horticultural/Operational

Prior to the Millennium drought, there had not been a great deal of consideration given to planting design. Triaging the collection was a consideration, however this was not simple in practice because of the duration of the drought, and the number of high-value conservation collections. Many of the collections were grouped together taxonomically, without regard to water requirements of individual species. As the drought progressed, the ANBG began to consider how plants could be better grouped to maximize water use efficiency; matching species from similar rainfall areas is one approach to leverage available water, noting the Gardens holds collections from across Australia, reflecting tremendously diverse climates (Figure 5.1).

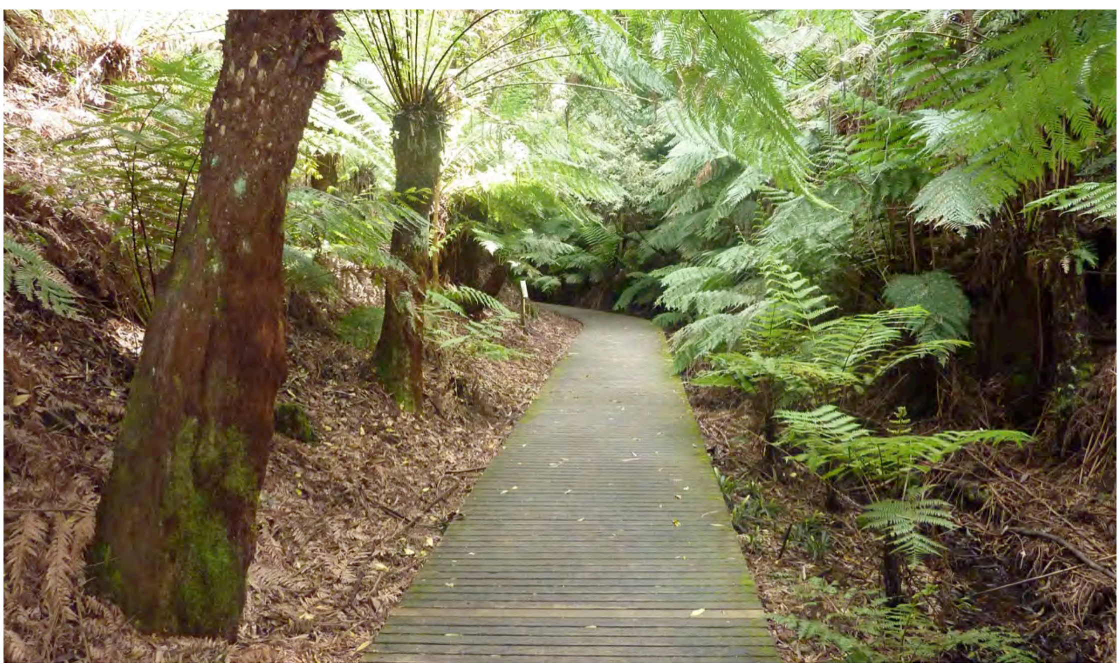


Figure 5.1 The Australian National Botanic Garden holds collections from diverse climates across Australia. (Rawson 2009)

The longer-term strategy for landscape succession planning is to bring more of the high value plants into the center of the Garden. In the event of severe water shortage, watering of the perimeter areas could be shut down or reduced. During drought periods when water is scarce, plants are kept alive, rather than kept thriving. Taylor adds that communicating to the public the impact of drought and water restrictions on landscapes is important.

Collections

The ANBG is reviewing its living collections policy, with a revised policy currently in draft form. The revised policy will pull together such things as consideration of the use and location of collections throughout the ANBG site, taking into account the challenges of the Canberra climate, their conservation value and role as ex-situ collections. The garden has very good documentation for a large proportion of its collection often with provenance data including descriptions of the collecting locality. This information, linked to climate data helps inform decisions about the most appropriate location within the Gardens for particular plants.

A large percentage of the plants at the ANBG have exceptional seeds, meaning the seeds cannot be stored long-term, and living plants are often the only way of conserving them *ex situ*. This adds another dimension to risk management, because backup germplasm cannot readily be conserved as seed. Sending important material to another institution as insurance against loss is one option to protect against loss of this germplasm. The ANBG actively exchanges plant material with a range of institutions, botanical and non-botanical. Taylor cautions that it takes a lot of effort and resources to ensure that comprehensive records go with the plant, and these records need to be maintained at each institution to retain information relevant to origin and genotype.

There is also the question of proper maintenance and care, Taylor observes that what may be a priority at one institution may not be at another, so any exchange agreements need to be properly managed.

> A huge number of the collection is exceptional, in fact the highest percentage of the living collection growing here at the ANBG has been grown by vegetative means. The majority of these plants are backed by an extensive range of information retained in our plant records system and linked to the individual living plant accession. This has facilitated many re-introduction and landscape enhancement plantings and means our partners and collaborators who are responsible for threatened species, conservation and land management have many options for partnering with us using our collection as a base for new plantings in the wild, particularly for species that can't readily be grown from seed. (David Taylor)

The acquisition and maintenance costs of some conservation collections can be considerable, giving further impetus to keeping those collections alive during times of water shortage. A collection made for conservation purposes will involve more work in the field, where individual plants may be collected as cuttings, documentation must be accurate for each plant, and this information must be tracked to ensure genetic diversity is recorded and maintained.

Taylor says it is important to identify the likely purpose of planned collections so that time and money are not spent on unnecessary complexity and documentation. For example, if the collection is for an educational display it does not need the intensive collection method needed for conservation collections requiring genetic diversity and clonally-tracked information.

> It comes down to the amount of time in the field to accomplish a conservation (or genotype) collection compared to one where you're just collecting a plant to have in your collection for display and education. (David Taylor)

New developments give the garden the opportunity to consider low water use plants and themes. For example, a garden bed development under consideration is a collection of plants from the Western Slopes of New South Wales, which is somewhat drier than Canberra, meaning many of those plants would be viable with little or no water.

Water Delivery / Infrastructure improvements

In 2010, with the approval of the local water authority, a pipeline was constructed to Lake Burley Griffin, approximately one kilometer from the Gardens, to supply non-potable water for irrigation. David Taylor reports that approximately 90-95% of the living collection now uses non-potable water. Furthermore, non-potable water was less expensive, and provides a more ethical and efficient method of water delivery. Water sensors have been installed in various areas of the Garden; backing up visual observation by horticultural staff, ensuring water is applied only when needed.

Expanding Water Storage Capacity

The Garden took a practical approach to expanding the amount of water intercepted and held on the site, with the installations of swales and surface sculpturing to capture and retain water. A redevelopment within one of the Myrtaceae sections concentrated the planting of Myrtaceae adapted to wetter conditions (for example, some *Melaleuca, Syzigium,* and *Leptospermum*) in and near swales to take advantage of increased moisture and thus requiring less additional irrigation. This is really about matching plants to site conditions and microclimates. Typically with redevelopments, opportunities are taken to break up hard surfaces, and where practical convert the sub-surface drains that directed water from pathways straight into the lake to above ground water harvesting swales and ephemeral creek lines. This enables water to be redirected to garden beds taking into account risk of pathogen contamination. Further water harvesting and storage and re-use is being investigated and remains an opportunity for all new works and site planning.,

Water Supply Policy

Dr. Sutherland notes that planning for a non-potable supply began before the Millennium drought, and the importance of maintaining the momentum with the various agencies involved cannot be understated. Multiple government agencies were engaged and negotiated with over a period of nearly 20 years. However, the opportune time for making the case for change with the relevant agencies was during the drought, when a higher value was placed on potable water and there was pressure on all to conserve water.

> Of course the drought drew much attention to water being an important resource, both across institutions and the region more generally as we were all impacted. Such impact really helps to move water-wise thinking and planning along (David Taylor)

The drought, and the urgent need for multiple Australian Capital Territory institutions to retain water supplies was a catalyst for approval to be granted for the ANBG to extract water from Lake Burley Griffin. Taylor adds that a comparison of the cost of potable and non-potable water is a useful exercise, particularly if escalating costs of potable water are factored in.

At the height of the drought, regular meetings were held between ACT institutions, including the ANBG, and the Australian Capital Territory Government to manage the impacts of the drought. It was vital to develop and maintain a good working relationship and clear communication lines with the authorities so the outcomes could be optimized.

> At the time of the peak of the (Millennium) drought, there was discussions about all the National institutions and public areas that were being supplied with water through Canberra, which water sources would have to be turned off or dramatically reduced, in line with different stages or levels of the water restrictions if they escalated… (David Taylor)

Risk Assessments of the likelihood and causes of water shortage

When asked about scenarios that might lead to long-term water shortage, climate change was nominated as a major factor; along with the associated erratic and more severe weather patterns already occurring.

> During that period of eight to ten year dry period in Australia, there was also a lot more discussion about climate change and long term implications, and in our department, climate change became a real focus, so yes, that was certainly a factor that fed into a renewed effort on water conservation and changes. (David Taylor)

How Planning was Undertaken

The ANBG did not use a specific consultant for any of the risk assessment or planning undertaken to address the issue of the impact of water shortage on the collection, rather it consulted widely, and in particular with other ACT (regional) institutions, with other botanical institutions, and with relevant authorities to determine irrigation systems that might deliver water more efficiently. The process evolved over a number of years, but the Millennium drought really focused efforts to find sustainable water solutions.

In terms of resources, as the drought took hold, and the risk to the collection became greater, more effort was devoted to finding solutions and options, with internal resources redirected to the cause. Taylor says that probably the biggest challenge was that virtually the whole site has high conservation value collections, making triage decisions complex.

Advice and reflection

Taylor emphasized how important it was to communicate the value and purpose of the collection to the ACT Government, to other Canberra institutions, and to the water supply authority. The key message emphasized the value of the living collection in terms of research, conservation and education, and due to the detailed provenance records, the collection is a critical asset for preventing species and landscape loss. The message was well received, the outcome leading to the ANBG being able to implement a more sustainable outcome and to extract water from Lake Burley Griffin, after more than twenty years of negotiations. Having been through the experience of such an extreme drought, the garden now, as standard practice, looks for opportunities for water harvesting, conservation and succession planning to better match plants to the site.

Taylor's advice to others is to be open and honest in sharing experience and challenges, and to share one's own knowledge and experience to provide opportunities for others is of great value. Really useful ideas and information was identified through speaking with other gardens and institutions and seeking out places with similar challenges.

ROYAL BOTANIC GARDENS VICTORIA MELBOURNE GARDEN

The Royal Botaic Gardens Victoria (RBGV) Melbourne Garden Director Chris Cole was interviewed by phone on November 16th 2015, and a second interview conducted on November 24th 2015. Peter Symes, Curator, Environmental Horticulture at Melbourne Garden also provided extra information and insights via email.

RBG Victoria comprises Melbourne Garden, the native Cranbourne Garden, the National Herbarium of Victoria, and the Australian Research Centre for Urban Ecology (ARCUE). Melbourne Garden is the subject of this case study.

Located on the southeastern edge of the city, adjacent to the Yarra River, Melbourne Garden dates back to 1846. The present landscape is largely the legacy of William Guilfoyle, who assumed the role of Director of the Garden in 1873. Guilfoyle gave the Garden a subtropical feel, with the use of palms, ferns, *Phormium* and *Cordyline*, and introduced sweeping lawns, panoramas, the ornamental lake and the Volcano. The Garden has 8,400 taxa in 30 plant collections, including the Araucariaceae family of conifers, Australian rainforest walk, Fern Gully, Guilfoyle's Volcano, and the New Zealand Collection. The Garden extends over 38 hectares (94 acres) of inner city Melbourne, bordered by the 46 hectare (113 acre) Domain Parklands managed by the City of Melbourne.

The City and the Botanic Garden are not connected administratively. The Royal Botanic Gardens Victoria is a statutory authority partially funded by the Victorian State Government, with an annual operating budget of around $18 million AUD, of which $14.7 million AUD is State funding, the bulk of the remainder being earned revenue and sponsorship (Royal Botanic Gardens Victoria 2015b). The City of Melbourne has an annual operating budget of around $0.57 billion, and assets of $3.85

billion (City of Melbourne 2015), and is Australia's second largest city, with a population of 4.4 million in Greater Melbourne.

Climate and Climate Change Impacts

Melbourne's climate is characterized by warm to hot summers; with an average of 30 days above 30 degrees C. Winters are cool, but not freezing. Rainfall is approximately evenly distributed through the year, but evapotranspiration rates are much higher during the warmer months, leading to a comparison with Mediterranean climates (Symes, Pers. Comm.). Table 5.2 summarizes Melbourne's climate data.

Table 5.2 Climate averages for the City of Melbourne, Victoria. (Australian Bureau of Meteorology 2016d)

Climate Averages – Melbourne, Victoria		
Average maximum summer temperature	25.3^0 C	77.5^0 F
Average minimum summer temperature	14.0^0 C	57.2^0 F
Highest recorded temperature	46.4^0 C	115.5^0 F
Average days per year > 30 deg C / 86 deg F	30 days	
Average days per year > 35 deg C / 95 deg F	10 days	
Average maximum winter temperature	14.2^0 C	57.5^0 F
Average minimum winter temperature	6.5^0 C	47.7^0 F
Lowest recorded temperature	-2.8 C	27^0 F
Average annual rainfall mm / inches	648 mm	25.5"

Drought and bushfire are the two most problematic kinds of natural disasters in the Melbourne region; the 'Black Saturday' bushfires of 2009 burned to within 52 km (32 miles) of the CBD, killing 179 people, destroying nearly 2,000 homes, and burning out 445,000 hectares (1,100,000 acres). Melbourne emerged from the Millennium drought experience with water and climate change management strategies integrated across State and Local Government agencies, water authorities and private stakeholders. For example, see Low and other's (2015) account of the actions taken to manage the City's water supply. The City of Melbourne has published a suite of strategies aimed at preparing the city for the projected impact of climate change. Documents include the City of Melbourne Climate Change Adaptation Strategy (Maunsell Australia 2009), City of Melbourne Urban Forest Strategy (City of Melbourne 2014b) and Watermark: City as Catchment (City of Melbourne 2014a).

By 2070, Melbourne can expect the number of hot days to double, a reduction in runoff into its water catchment of up to 50%, and a decline of up to 19% in the number of rain days. Urban Heat Island effect is already responsible for average temperature being up to 4 deg C higher in the CBD than the suburbs, and up to 7 deg C higher during hot weather (Wales et al. 2012). Melbourne Garden, being adjacent to the CBD, is within the Urban Heat Island zone of elevated temperatures. Sea level rise could also be a problem, with the low-lying Port Phillip Bay area where the Melbourne Garden is located particularly at risk (Wales et al. 2012). The city's main water supply is harvested rainfall, with storage reservoirs having a combined capacity of 1,812 giga liters (1.47 million acre-feet). Storage levels across the network dropped to the historic low of 25% of capacity in 2009, just prior to the drought breaking. Inflows during the drought were nearly 40% below the long term average, as shown in figure 5.2.

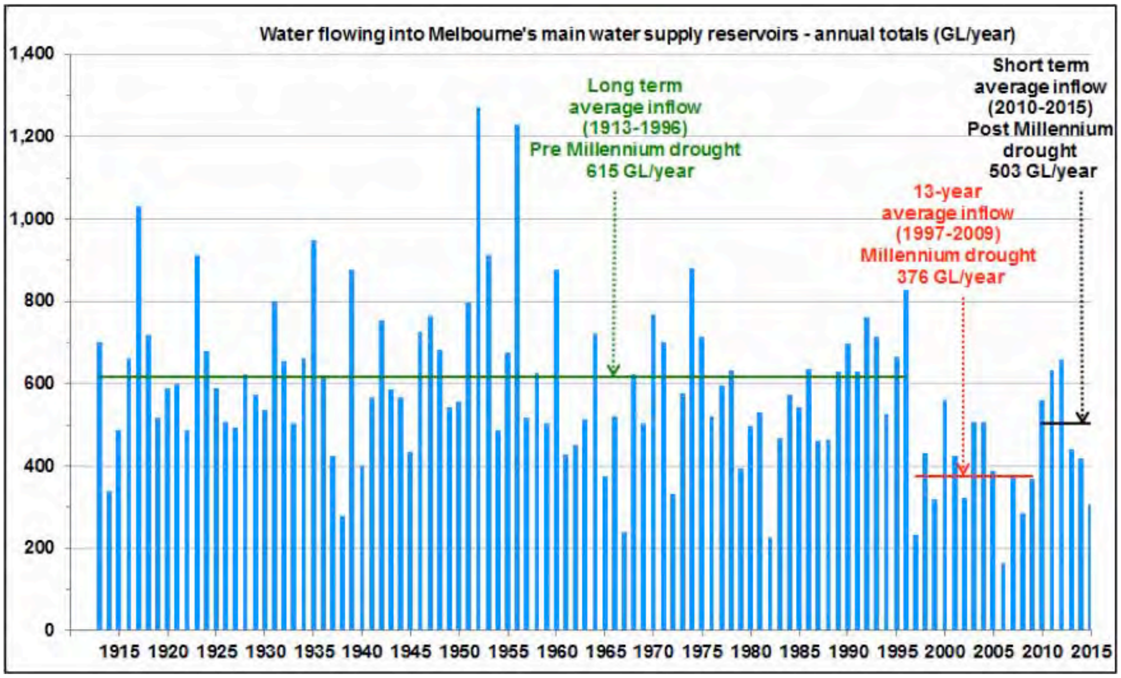


Figure 5.2 Long-term inflows to the Melbourne water catchment. The impact of the Millennium drought on water inflows is evident. The green line is the long-term average of 615 GL/year between 1913 and 1996, the red line is the Millennium drought average of 376 GL/ year between 1997 and 2009. Source: Melbourne Water (2015)

Planning Elements

While this section itemizes different elements of planning, it should be noted that Melbourne Garden has a very integrated and strategic approach to plant collections and water management, and none of the different approaches have been undertaken in isolation.

Horticultural and Operational

Staff training in irrigation management was undertaken shortly after the automatic irrigation system was installed, resulting in demonstrable water savings. Employees were trained in soil hydrology, weather and climatic factors, and plant physiology. Training in irrigation and water management continues to be a feature of the horticultural operations at Melbourne Garden. The Garden has long had research partnerships with students and academics at the University of Melbourne and Monash University, who utilize the site to test academic theories of urban horticulture and freshwater ecology. Research outcomes can be utilized at the Garden, for example, it was found that effective rainfall - the amount of rainfall that infiltrates into the ground - is influenced by the size and depth of mulch in garden beds, and by vegetation canopy interception. Coarser mulch is now preferred to allow better water penetration, and is maintained no deeper than 5cm (2") to ensure water is not intercepted and held by the mulch layer (Symes, Pers. Comm.).

The Irrigation Management Plan documents the horticultural practices used to better cope with dry conditions, most of which are also utilized to help conserve water under 'normal' conditions. Significant improvement in efficiency has been gained from the development of irrigation scheduling linked to specific landscape coefficients and reference evapotranspiration for each hydro-zone (Symes, Pers. Comm.). Some of the recommendations from the Irrigation Management Plan have been simple to implement, others, such as planting similar water requirement plants together are longer-term aspirations. The practices, from Symes (2002) are:

- Re-prioritize and limit projects to major living landscape and living collection developments only
- Schedule projects and maintenance programs to ensure planting is undertaken during autumn-winter so that plants can reach optimal root establishment over the cooler and wetter months prior to temperature increases and subsequent higher water demand
- Set final dates for new planting during autumn-winter

- Group plantings of similar irrigation requirements together within a common hydro-zone

- Minimize or cease the application of fertilizer prior to summer or predicted dry conditions to prevent lush plant growth (although applications of slow release nitrogen in spring can assist turf resilience)

- Pre-apply wetting agents to known hydrophobic zones and throughout drought season as needed to improve water infiltration during drought

- Prior to anticipated drought conditions, increase the soil water reservoir to field capacity down the soil profile to subsoil depths (up to 600 mm) by deep irrigations

- Regularly assess moisture levels at depth by monitoring the soil profile

- Increase irrigation scheduling intervals as possible to promote plant resilience and deep root development

- Minimal pruning during drought conditions

- Increase general mowing heights of turf to 50-75 mm or mower limits (particularly for cool-season species) or cease mowing of selected areas

- Regular de-thatching and aeration of turf priority areas to improve water infiltration (particularly for warm-season species)

- Ensure mulch coverage of all bare soil areas to reduce evaporation losses.

Turf grass is a big user of irrigation water, about 65% of all Melbourne Garden's irrigation according to Symes (2002). Converting the turf species to the deeper rooting, C4 photosynthesis warm season grasses including Kikuyu (*Pennisetum clandestinum*), Common Couch (*Cynodon dactylon*), and Buffalo Grass (*Stenotaphrum secundatum*) was expected to save around 20 megaliters of water per year with the adjustment of the turf irrigation crop coefficient programed into the automatic irrigation system.

Collections Adaptations

Melbourne Garden's Living Plant Collections Plan (Royal Botanic Victoria 2015a) encompasses scientific, educational and horticultural aims:

- To display and interpret living plant collections with significant scientific value on a regional, national and international level.
- To support priority plant conservation programs through *ex situ* cultivation of threatened taxa.
- To demonstrate RBGV responses to climate change and management of landscape transition to ensure provision of these Garden for future generations.
- To highlight the picturesque and gardenesque landscape style and associated ornamental plantings of Melbourne Garden.
- To stimulate, challenge and educate visitors about contemporary environmental and cultural issues and reflect the influences of our cultural heritage.
- To pursue horticultural excellence in the management of our living collections.

The most recent planning document is the "Landscape Succession Strategy 2016-2036" (Royal Botanic Gardens Victoria 2016). This plan takes a strategic approach to managing the botanic landscape through the anticipated climate change impacts of a hotter and drier climate using five measurable strategies. The Strategy's goal is to "provide future visitors to Melbourne Garden with a place of beauty, biodiversity and refreshing green space in a changing climatic environment". The challenge is to maintain the heritage character of the Garden and visitor amenity in the face of hotter conditions, while transitioning to a different palette of climate-suited species. The Landscape Succession Strategy's five goals are:

- Actively manage and transition the Melbourne Garden landscape and plant collections. By 2036, 75% of taxa are suited to the projected climate of 2090.
- Establish a mixed-age selection of plants composed of a diversity of taxa. By 2036, plant diversity is equal to or greater than 8,400 distinct taxa of mixed-age, with greater than 35% wild sourced plants.
- Maximize sustainable water availability and use. By 2020, 100% of landscape irrigation is obtained from sustainable sources.
- Maximize the benefits of green space and built environment through landscape design. Improve green and built infrastructure to mitigate and withstand predicted climatic extremes.
- Improve understanding of the impacts of climate change on botanical landscapes. Communicate to colleagues and the community on the benefits of plants in a changing climate. (Royal Botanic Gardens Victoria 2016, 5)

The future climate of Melbourne is compared with a range of locations under several climate scenarios, the aim being to compare localities with similar climates, and therefore plants, which will be suited to Melbourne's future climate. One challenge is the occasional extreme temperatures experienced in Melbourne belie the otherwise seemingly benign average climate. Heatwaves in 2005, 2006, 2009 and 2014 saw temperatures exceed 40 degrees C on 14 occasions, the highest temperature recorded at Melbourne Garden being 46.7 C (116 F) in 2009. For example, Cape Town's historical climate has very similar average winter and summer temperatures as Melbourne's projected 2030 climate, but the South African city has never officially recorded temperatures over 40 degrees C.

Cole notes that plant collections data was not as accurate as it could have been, and there has been a concerted effort to improve data quality, with curators now spending up to one day per week on mapping and documenting their collections.

> It really helps inform the Landscape Succession Strategy, how do you determine the proportion of unsuitable taxa in the gardens, if the plant records are not accurate and up to date? This is a critical baseline.

Elements of some collections have begun to be transferred to cooler, wetter gardens in the Dandenong Ranges in Victoria. The Southern China collection, for example, is a valuable collection in terms of not only its conservation value, but also the amount of time and effort that has been expended curating and maintaining the collection over many years. Much of this collection will not survive the increase in extreme heat days in Melbourne, even if sufficient water is applied.

Water Delivery Infrastructure Improvements

The Garden's current irrigation system was installed in 1993-94, at a cost of more than $1.3 million. This system has over seven km of water mains and more than 40 km of sprinkler pipes, and with subsequent extensions, now has around 18 satellite controllers, 9,300 sprinklers and about 500 active solenoid valves. The system is automatic, and continues to be upgraded with more efficient components. The automatic irrigation system, and skilled staff to operate and oversee it, is central to managing water delivery as efficiently as possible; programed to irrigate according to an irrigation index algorithm, moisture sensors and regular monitoring ensure the system delivers water as efficiently as possible.

The Garden continues to improve irrigation efficiency, with upgrades to the system enabling better flow management, and higher water pressure allowing flexibility to delay irrigation scheduling to take advantage of forecast rainfall. Symes

(2009) points out that a 10mm effective rainfall event has the potential to save up to 3.8 million liters of irrigation water if irrigation scheduling is delayed to anticipate forecast rainfall; or $11,000 in today's dollars (Peter Symes. 2016, Pers. Comm.).

The 'Working Wetlands' project, capturing and treating stormwater from streets bordering the Garden was completed in August 2012. This project arose from the 1997 Master Plan, where improving the health of the lakes systems, and the renovation of the old reservoir, known as 'Guilfoyle's Volcano' were identified as priority projects. The Working Wetlands project combines these two projects into an elegant water recycling system. Captured stormwater is directed through gross pollutant traps and then into wetlands to remove nutrients and sediment, before being circulated through the lakes system. Floating treatment wetlands are a practical feature of the scheme in the Volcano and the Ornamental Lake; water is circulated via a pump, and the floating wetlands further assist with nutrient removal (figure 5.3). Water is ultimately filtered, UV disinfected and pH adjusted, but only chlorinated if there is an additional risk to operators. The water is then stored in four above ground tanks with a total capacity of 0.5 ML (132,000 gal.). The Working Wetlands scheme has resulted in a reduction in the level of Nitrogen and Phosphorus in the lakes, bioavailable phosphorous levels are now about 80% less and bioavailable nitrogen 50-7-% less (Peter Symes. 2016, Pers. Comm.). These reductions have reduced the extent and the duration of the problematic blue-green algae blooms, and seen a better retention rate of water over summer.

Figure 5.3 Guilfoyle's Volcano, part of the Melbourne Garden's stormwater harvesting project. Note the floating wetlands, a practical and attractive feature of the scheme. (Source: RBG Victoria).

Funding for the AUD$6.5 million capital cost of the project was provided from donors, sponsorship and government sources, with construction occurring over three years, in three stages. The Working Wetlands can direct up to 52 ML per year of harvested stormwater to irrigate the Garden, resulting in a reduction of potable water use of up to 40% annually. The system has the capacity to treat and irrigate over 2.0 ML of lake water in 12 hours if required (Peter Symes. 2016, Pers. Comm.) Lake water is also ‘emergency’ water, in the event that municipal water is unavailable, with the ability to switch pumps to generators. Water stored in the Volcano can also be gravity-fed to supply water to important collections.

A partnership between the Garden, the University of Melbourne, and Sentek Technologies is researching how deep the water uptake zones of trees extends, to determine if harvested stormwater can be also stored directly in the soil during winter, and extracted by those trees later when needed (Symes and Connellan 2013).

Policy and Pricing

Prior to 1998, the Garden was not charged for potable water, but following changes to the water industry regulations, now pays for all its potable water. Melbourne Garden currently pays $3.142 per kiloliter for potable water, and in recent years has used between 40.4 ML and 126 ML per annum, the amount varying according to the rainfall amount and timing. The garden’s annual water bill in the past five years has ranged between $188,000 AUD to $260,400 AUD.

The Garden has a productive working relationship with the local water retailer, South East Water, and bulk water distributor, Melbourne Water. In Australia, new licenses to extract water for commercial use from waterways are no longer issued, with existing licenses retired or traded on a secondary market, depending on the river valley and the available water. A group of agencies, including the City of Melbourne and Melbourne Garden were able to take up a relinquished water license, granting 2,200 ML (1784 acre-ft) of water per annum from the Yarra River. Melbourne Garden’s share of this water is 100 ML, which is sufficient for all gardens irrigation needs when combined with the Working Wetlands water. Funding is now being sought to construct a pipeline to divert the water from above the Yarra River tidal zone to downstream users, with Melbourne Garden's share of the cost estimated to be $3-4 million This will help secure the water supply for Melbourne's Urban Forest, Melbourne Garden, and urban parks, when coupled with other water efficiency and capture and reuse projects. The cost to Melbourne Garden was $600 to transfer part of the water license; Director of Melbourne Garden, Chris Cole, notes that the long history of communication and relationship building with Melbourne Water and the City of Melbourne ensured this positive outcome.

> It cost a minimal amount to get the water rights transferred, helped by the very strong relationships with water retailers and the water authority developed during the Working Wetlands project, and indeed since we started on this integrated water management journey in the early 2000's, we've always kept our contacts very close, and they've been involved on Project Control Groups through the Working Wetands Project. We know the individuals well, and the companies have a very good relationship with us, it also provides a good flagship project for them. Those water retailers have given us some sponsorship money to enable the programs that we deliver today. It's just a continuation of that relationship really.

Risk Assessments

A business continuity plan deals with a range of business risks across the operation, including short-term water shortage, in the event of irrigation system failure for less than one week. In terms of long-term planning, the Garden uses science from the Australian Bureau of Meteorology, and CSIRO, basing risk analysis on the science and the knowledge of previous events, such as the Millennium drought and the trend towards hotter temperatures.

> We're very firm believers in climate change… the whole organization here is very serious about climate change and what we need to do in the face of it. I'd say that's one of the biggest triggers, and also recognizing our role as caretakers, or stewards of a world-renowned botanic gardens, it's our responsibility to do something, and not just to sit back and think it will be aright. It's essentially setting the gardens up for future generations.

How Planning was Undertaken

Much of the Garden's planning is undertaken by a core group of staff, including the Director of Melbourne Garden, Landscape Architect, Curator Environmental Horticulture, and Manager of Horticulture. The Garden has developed increasingly more detailed and strategic plans, beginning with the development of a living collections policy in 1995. The 1997 Master Plan (Royal Botanic Gardens Melbourne 1997) followed. These two documents were the first in a series of planning instruments to be developed, and which continue to be reviewed and refined. By the time the Master Plan was reviewed and updated in 2008 (Barley et al. 2008), concern with the impact of climate change, and the availability and cost of water was evident. Climate change was not mentioned in the 1997 Master Plan; however, the impact of the Millennium drought, and climate change modeling for a hotter and drier Melbourne climate was reflected in the 2008 Master Plan Review. The Garden also produced the comprehensive Irrigation Management Plan (Symes 2002), and later, a Strategic Water Management Plan, developed in response to the Victorian Government's environmental monitoring and reporting requirement. The Landscape Succession Strategy (Royal Botanic Gardens Victoria 2016), released in 2016 is a continuation of this planning effort.

Collaboration with City of Melbourne and Melbourne Water

The City, Melbourne Water, and Botanic Gardens Victoria collaborate to improve the urban environment, while reducing demand for potable water from parks, gardens and street trees. The Millennium drought triggered an accelerated loss of tree cover across the City of Melbourne. Since then, the City has developed a comprehensive plan, the City of Melbourne Urban Forest Strategy 2012-2032 (City of Melbourne 2014b), to manage its trees in the face of the warming and drying climate, aiming to increase canopy cover from the current 22% to 40% by 2040. The plan also addresses species diversity, just three species made up more than 35% of trees when the plan was implemented in 2012. This diversity is important to prevent catastrophic loss of canopy from imported pest and diseases, such as Dutch elm disease (DED) or Myrtle rust. The Strategy aims to achieve an urban forest by 2040 with no more than 5% of any tree species, no more than 10% of any genus, and no more than 20% of any family.

The Urban Forest Strategy also commits the City to ensuring the urban forest will have sufficient water to provide for healthy growth. The benefits of the urban forest strategy are manifold, but certainly the environmental benefits were at the forefront during planning. For example, shading and transpiration from additional healthy tree cover will provide a measurable reduction in the urban heat island effect, and a reduction in the energy used for cooling by householders and businesses. A well-managed urban forest is expected to reduce stormwater and nutrient run-off, helping to counteract the impact of an increase in heavier rainfall events. The City has committed to a holistic urban forest development timetable that includes not just 'street tree planting', but also capital works programs to capture and reuse storm-water, development of 'sewer mining' plants for urban parks, and collaborating with

Melbourne Garden, and other agencies to fund the installation the Yarra River pipeline.

Advice and Reflection

Chris Cole maintains that the Garden's approach to integrated water management and planning was due in large part to the efforts of Peter Symes, the Curator, Environmental Horticulture.

> The whole approach comes down to Peter (Symes) at the end of the day… He's been collecting data for over 10 years, and it really shows some strong trends and support for the all the work he's done over that time, so what may have seemed like a bit of a chore at the time, in terms of collecting data and monitoring, once that starts to build into a healthy data set, it really does paint a very powerful picture.

Symes counters that the organization's commitment to team work and professional development was crucial in the formative years, and horticulture and plumbing staff instrumental in ensuring delivery of efficiency gains (Peter Symes. 2016, Pers. Comm.). Coincidentally with the change to water charging came the beginning of the Millennium drought, and the necessity to demonstrate to South East Water and Melbourne Water that the Garden was working towards measurably more efficient water use. The monitoring, measuring and strategizing undertaken over twenty years ensured Melbourne Garden wasn't put onto stringent water restrictions during the drought, although the cost of potable water also provided a big incentive to continue working to use it as efficiently as possible, and also to seek out alternative supplies.

The Garden's strategic approach to planning has resulted in an organization that is now very well placed to manage the impact of climate change, giving itself time to redevelop its living collection in the face of a warmer and drier climate.

ROYAL TASMANIAN BOTANICAL GARDENS

The Horticulture Coordinator at the Royal Tasmanian Botanical Gardens (RTGB), David Reid, was interviewed at Wollongong on October 26, 2015, and again by telephone on December 17. Several clarification emails were also exchanged between October and December 2015.

Royal Tasmanian Botanical Gardens (RTBG) is located adjacent to the Derwent River and the Queens Domain parkland, on the northern edge of the City of Hobart, Australia's most southerly city. Hobart is located at 42.5^0 S, about the same latitude from the equator as Boston, but sub-zero (sub 32^0F) temperatures are very rare in Hobart; Table 5.3 details the city's climate averages.

Table 5.3 Climate data for Hobart, Australia. Source: Australian Bureau of Meteorology (2016c)

Climate Averages – Royal Tasmanian Botanical Gardens		
Average maximum summer temperature (January)	21.7^0 C	71^0 F
Average minimum summer temperature	11.9^0 C	53^0 F
Highest recorded temperature	41.8^0 C	107^0 F
Average days per year > 30 deg C	6.3^0 C	
Average days per year > 35 deg C	1.2^0 C	
Average maximum winter temperature (July)	11.7^0 C	53^0 F
Average minimum winter temperature	4.6^0 C	40^0 F
Lowest recorded temperature	-2.8^0 C	27^0 F
Average annual rainfall all years of data Past 10 year average 2006-2015	523 mm 463 mm	20.6" 18.2"

Natural disasters of concern in the Hobart area are bushfire and drought. The worst bushfire on record was the 'Black Tuesday' bushfire of 1967, which burned to within 2 km of central Hobart, killed 62 people and burnt out 265,000 hectares (655,000 acres) (Australian Bureau of Statistics 2010). While Hobart is in a relatively low rainfall area, rainfall increases dramatically in the far west of the city's water catchment, and until very recently, water shortage in this part of Tasmania was not considered to be a problem. The city's water is sourced from rainfall in the 8,200km^2 (3166 sq. mi.) Derwent River catchment, where average annual rainfall in the upper catchment rises to 1800mm (70"), compared with 550mm (21.5") at Hobart. By the beginning of 2016 however, unprecedented below average rainfall and increased temperatures (Australian Bureau of Meteorology 2016f) saw water storage levels in the State's hydroelectric dams fall to record low levels (Parkinson 2016).

Founded in 1818 to serve as a trial garden for economic plants, the Botanical Gardens developed its extensive conifer collection in the 1800's, and now has a focus on cool temperate flora from Tasmania and the southern hemisphere, with around 6,000 taxa in total. The world's only sub-Antarctic plant house displays flora of Macquarie Island, the Tasmanian nature reserve located 1294 kilometers north of Antarctica and a sub-Antarctic collection. The garden has significant collections of Tasmanian flora, including ferns and southern heaths. Other collections include a Japanese garden, palm collection, plants from China, Cactaceae, and the Community Food Garden. The Community Food Garden is an organic demonstration garden, interpreting sustainability and food security, providing educational and volunteer opportunities to the people of Hobart. The Tasmanian Seed Conservation Centre, part of the Millennium Seed Bank Project, is the RTBG research and plant conservation section. The Centre collects and conserves Tasmanian flora, with duplicates sent to Kew. The adjacent 200-hectare (494 acres) Queens Domain parkland ('the Domain') compliments the fourteen-hectare (35 acre) botanical garden. The Domain landscape is a mix of natural grasslands, conifer and *Eucalyptus* plantings, and several small sporting venues and is mostly situated on an elongated hill, reaching up to 135 meters in elevation. The RTBG lies at the foot of the Queens Domain hill, and adjacent to the Derwent River, elevating from sea level to 30 meters. The Domain is administered by the City of Hobart, however the Gardens, and Government House grounds adjacent to the Gardens are administered by the State of Tasmania

The Gardens’ 2015 annual budget was about $4.2 million, of which $2.72 million was funding received from the State of Tasmania. Security of funding is an issue, with the State reducing its grant funding, and income from business enterprises falling, the Gardens has reduced employee numbers and restructured some visitor services arrangements ensure the budget is met. The Gardens has a total of thirty three employees, eighteen of whom work directly in Horticultural Collections and Research division, the remainder in administration, marketing, visitor services, facilities and education.

A risk analysis undertaken by the Gardens identified severe weather (storms), bushfire and flooding as the three main natural hazards (Royal Tasmanian Botanical Gardens 2008). For instance, a severe storm in 2008 caused significant damage or death to more than sixty trees in the garden, and flooding from stormwater after heavy rain is a problem. Hobart is surrounded by natural areas, and has a long history of bushfire in the region. The Gardens’ location directly adjacent to the natural areas of the Queens Domain heightens the threat of bushfire during dry weather. A bushfire burned 20 hectares of the Queens Domain, adjacent to the Gardens in January 2013 (figure 5.4). The danger of bushfire adds another layer of risk when planning for water shortage at the Garden.

Figure 5.4 Fire in the Queens Domain, January 2013 burned very close to the Botanical Gardens. Source: ABC News (2013)

Hobart was affected by the Millennium drought and below average rainfall for most of twelve years of that drought; water restrictions were imposed over three very dry summers from 2007, partly to ensure the city's reservoir levels retained sufficient water in the event of bushfire. Reid (Pers. Comm.) reports the annual rainfall of 530mm is adequate, along with backup water from the Hobart supply, to maintain the current collection. The water management problem for RTBG is the cost of irrigation water, in addition to periodic water restrictions and its somewhat precarious budget situation; water charges of up to $60,000 per year are unsustainable. Storms have been more frequent in the past ten years, with strong winds closing the garden four times in the past seven years.

Planning Elements

Horticultural/Operational

The Millennium drought prompted some simple but effective changes to operational and horticultural practices. A commitment was made to regularly maintain the irrigation system, and ensure regular monitoring of the weather forecast to ensure the system is shut off if rain is forecast. Water meters within the gardens are read every two weeks, the data used to set goals for improvement over previous readings. The greater knowledge of when, and how much water is being used helps to reduce waste. Lawns are now mowed higher to help shading of the soil, and in some areas the lawns are allowed to brown off.

Collections

The completion of the Living Collections Plan (Inspiring Place Pty Ltd 2009a) was a prerequisite document for the Strategic Master Plan. Its purpose was to provide a strategic framework for the management of the collection, including its purpose, and policies around future development. The Master Plan's first strategic goal, "To sustainably manage the core values of the RTBG as Tasmania's botanical garden" and the strategies around this goal demonstrate a new focus on Tasmanian and conservation collections

- To ensure the RTBG is internationally recognized for its collections of southern hemisphere cool climate plants with a particular emphasis on Tasmania's flora. (Strategy 1.1)
- To support and be involved in world flora conservation programs (Strategy 1.3)

- To engage in appropriate research related to the conservation of species of conservation significance from southern hemisphere cool climate areas with a particular emphasis on Tasmania's flora (Strategy 5)

The value of individual collections was assessed by the RTBG Living Collections working Group using a matrix to score three classes of attributes: 'defining attributes', 'use attributes' and 'managerial attributes'. The higher priority on conservation and provenanced collections is reflected in how the value of the collections was appraised and attributes weighted, with more weighting for Tasmanian and Australian flora, and collections of provenanced threatened species, representative genotypes, known wild provenance, and representative taxonomic collections. The complete table of assessment attributes and the collection assessment is at Appendix D. The end result was an objective assessment of the value of each collection according to the RTBG's criteria, enabling decisions about each collection to then be made within the value framework. In the event of a natural disaster such as a drought, prioritizing which collections to focus resources ought to be relatively straightforward, with the Sub-Antarctic collection (68.5), Tasmanian Native Garden (67.5), Potted Conservation Collection (62.5) and the Conifer Species Collection (62) rated highest.

Several collections were de-accessioned and removed as a direct result of the review, including the *Protea* and Rills beds, with others recommended for removal, including ornamental conifers. Reid notes that removing plants of little value frees up resources (including water) to better focus on more important collections.

Water Delivery / Infrastructure improvements

An irrigation audit was undertaken across the whole garden, highlighting areas for improvement. Changing to more efficient irrigation heads, correcting over spraying and overwatering, and the installation of solar powered irrigation controllers in areas without electricity were simple but effective changes. Prior to controllers being installed, manual sprinklers were often left on for much longer than necessary. Monitoring of water use via the regular water meter readings also helped to quickly detect leaks.

Expanding Water Storage Capacity

A Master Plan completed for the Queens Domain proposes a comprehensive water sensitive urban design (WSUD) strategy, which includes capturing, treating and storing stormwater from various locations across the 200-hectare site. Currently stormwater runoff from the Queens Domain flows into and across the Gardens unchecked, so the Gardens would be a beneficiary from fewer stormwater incursions, as well as having a free source of water. This project is still in the planning stage, with no budget or date set as yet for work to commence.

Water Supply Policy

The Gardens does not get any relief from volumetric water supply charges, and does not have the benefit of the long association with the water supply authority that Melbourne Gardens and the ANBG has. Tasmania's water supply authority evolved from a series of mergers of local government and bulk water suppliers, with Taswater commencing operations as the State's main bulk and potable water supplier in 2013. The corporation is so new there has not been sufficient time to build a good working relationship or to initiate a cooperative research partnership. Taswater is responsible for water delivery for most of the State of Tasmania, and has a diverse range of functions compared with other capital city suppliers in Australia, it will be more difficult for the Gardens to set up any sort of effective partnering because of the diffuse nature of the corporation.

A Water Efficiency Policy (Sturges 2010) formalized the necessary and practical tasks in ensuring good garden stewardship:

- The irrigation system is kept in good repair
- Water meters are regularly monitored
- Garden beds are kept mulched
- Plants with similar water needs are planted together
- Plant selection recognizes water demand and tolerance to heat
- Staff are trained to carry out the water conservation strategies
- Turf and landscapes are managed to encourage water efficiency
- No watering between 10am and 3pm
- Lawns and gardens are watered less often but more deeply.

Risk Assessments of the likelihood and causes of water shortage

Currently the Gardens' biggest water shortage risk is lack of money to pay for water (David Reid. 2015, Pers. Comm.). Annual Reports (2012; 2014) catalogue a succession of funding cuts, and cuts to staff numbers. The other identified risk, and a scenario likely to eventuate more frequently with climate change, is severe and prolonged drought leading to water restrictions. The Strategic Master Plan includes climate change considerations in the appraisal of landscapes and collections, noting that some collections will not survive warming or drying (Inspiring Place Pty Ltd 2009b).

The Planning Process

The Royal Tasmanian Botanical Gardens Act 2002 (Tas) directs the preparation of a ‘Strategic Master Plan’ (Section 9), including a statement of the ‘intended long-term use, planning, management, conservation and enhancement of the botanical gardens’ (Section 9.2b). The Strategic Master Plan must also be reviewed at least once every five years (Section 14.1). The statutory obligation to prepare and review a Strategic planning instrument led to a suite of planning documents completed in 2009, including the Strategic Master Plan Royal Tasmanian Botanical Gardens (Inspiring Place Pty Ltd 2009b), and the Royal Tasmanian Botanical Gardens Living Collections Plan (Inspiring Place Pty Ltd 2009a). The Master Plan identifies the living collection as the primary purpose of the garden, contributing to its cultural, heritage, conservation, recreation, education, and place values. Climate change is noted as a threat to the living collection. A warming or drying climate could impact the Gardens' ability to grow cool climate plants for example, and could significantly change the composition of the living collection.

The initial strategic planning was conducted by a consultant; with support from in-house expertise, and subsequent planning reviews and updates have been done by the RTBG. The Living Collections Plan was a collaborative project between the planning consultant, the RTBG Living Collections Working Group and the Director of Dunedin Botanic Gardens in New Zealand and took two years to complete. Frequent consultation and collaboration occurs with Hobart City Council (Queens Domain, Figure 5.5) and the Department of Primary Industries, Parks, Water and Environment (DPIPWE), the Tasmanian Government Department under which the Gardens is grouped.

Figure 5.5 The Royal Tasmanian Botanical Gardens, showing the much drier Queens Domain in the background. Image: Fran Jackson

Advice and reflection

The Master Plan and the Living Collections Plan was key to creating a planning framework for the future. The process enabled the Gardens to recognize that the collections need to evolve to reflect current and future needs and circumstances. The process put a value on the collection, using criteria based on the strategic direction of the Gardens. As a result, the Garden has a deep and objective understanding of where to focus living collections resources. Data pertaining to the collection is also comprehensive and up to date, the Gardens having taken a strategic decision to retain the Curator's position through various episodes of imposed cost cutting.

UNIVERSITY OF CALIFORNIA BOTANICAL GARDEN AT BERKELEY

Telephone interview held with Dr. A. Christopher (Chris) Carmichael, Associate Director of Collections and Horticulture, University of California Botanical Garden at Berkeley. Interviews conducted December 23 2015 and December 29 2015.

The University of California (UC) Botanical Garden at Berkeley is located in the San Francisco Bay area of California. This region has a markedly seasonal, Mediterranean climate, with barely any rainfall falling in the five warmest months of the year (Table 5.4). The State of California has experienced increasingly severe drought since 2012 (State of California 2016); a state of emergency was declared in January 2014, (Brown 2014) and following record low snowpack in the Sierra Nevada, mandatory water restrictions were imposed across the State in April 2015 (Executive Department State of California 2015). Tree-ring research indicates the 2012-2016 droughts in California and Nevada could be the driest in more than 500 years (Belmecheri et al. 2016).

Table 5.4 Climate data for Berkeley, California. Source: Intellicast (2016)

Climate Averages –Berkeley CA		
Average maximum summer temperature (September)	21.7^0 C	72^0 F
Average minimum summer temperature	11.9^0 C	56^0 F
Highest recorded temperature (June)	41.8^0 C	107^0 F
Average maximum winter temperature (January)	11.7^0 C	56^0 F
Average minimum winter temperature	4.6^0 C	44^0 F
Lowest recorded temperature	-2.8^0 C	25^0 F
Average annual rainfall mm	645 mm	25.4”
Average annual rainfall wet season months (Oct, Nov, Dec, Jan, Feb, Mar, Apr)	32 mm	1.3”
Average annual rainfall dry season months (May, Jun, Jul, Aug, Sept)	612 mm	24.1”

In addition to drought, other natural disasters the region has to contend with are wildfire, storms, mudslides and earthquake. The Hayward fault, one of several major fault lines in the area, runs through Berkeley, parallel to the coast. This fault triggered a magnitude 7.0 earthquake in 1868 in the Oakland and Hayward districts, causing widespread building damage and killing thirty people (Brocher et al. 2008). The San Andreas Fault, on the other side of the San Francisco Bay, triggered the 1906 magnitude 7.8 earthquake; responsible for 3,000 deaths and $524 million in property damage, much of it from the ensuing fire in the city of San Francisco (Stover and Coffman 1993).

The Garden is located at the western side of the Oakland Hills, a range of hills with steep canyons prone to wildfire. Wildfires occur regularly in the region; for instance, the devastating Oakland Hills Wildfire in 1991 began one canyon to the south of the Garden, killing twenty five people and destroying nearly 3,000 homes (City of Berkeley 2016).

University of California Botanical Garden at Berkeley was originally established in 1890 to display a collection of plants from the State of California. Since then the 34 acre (13.7 Ha) garden's living collection has grown to nearly 13,000 taxa, with 19,300 accessions of plants from Mediterranean climates of the world. Collections include plants of Asia, Australia, Eastern North America, Mediterranean, Mexico, Central America, South America, South Africa and New World Desert (figure 5.6). The Garden has an important collection of ferns and fern allies (690 accessions), including xerophytic ferns, in addition to the expected plants from Mediterranean and arid climates such as Cactaceae (2029 accessions), Asteraceae (1,002), Liliaceae (1,097) and Orchidaceae (1,030) (UC Botanical Garden at Berkeley

2015). The Garden also grows three water intensive collections, East Asian, Eastern North American and Central American cloud forest. One third of the annual budget of approximately $2.7 million is derived from the University, the remainder from grants, membership, donations, endowment and revenue. Out of a total of thirty-three staff, eighteen work in horticulture and curation.

Figure 5.6 Collections near the entrance to the garden. Source: UC Botanical Garden at Berkeley.

Planning Elements

Horticultural/Operational

An increasing use of mulch, including chipped material and gravels, is helping to improve water use efficiency.

Collections

Sixty percent of the Gardens' accessions are wild-sourced, with good documentation. Data about the collection in general is also up to date and reliable. The collections management plan has the structure to inform decisions about what to collect, what to retain, and the likelihood of being able to reacquire material if need be. Backing up the collection is critical not just for water shortage, but the more immediate threat of fire.

Chris Carmichael (2015, Pers. Comm.) reports that the East Asian collection would receive high priority in the event of catastrophic loss (for example, from fire or water shortage). There are valuable type species of cactus in the collection; the question of what to do to manage the risk to these collections has not been resolved. The option of sharing germplasm, of backing it up elsewhere, has been considered, but not yet pursued as a formal part of the collections management strategy. The question of where to send material is one which has not been resolved either. The Asian collection, for example, needs plenty of water, and a climate without high or low extremes of temperature. The Cycad collection is part of the Plant Collections Network Cycad collection, so it may be possible to work with other member gardens in the network to insure the survival of germplasm of some of this collection.

The Gardens has not given serious consideration to changing its collection focus, however Chris Carmichael (2015, Pers. Comm.) acknowledges that this is something the Garden may have to contend with in the future. The use of woodland plants such as *Trillium* or bloodroot, plants that need additional water to grow well at Berkeley, has been discontinued.

> We said let's take a break and not push this one, they probably need more water, and now is not the time for more water. (Chris Carmichael)

Watering of the ‘small lawn’ ceased in 2015, the Garden signposted why the lawn was ‘abandoned’, but have not yet decided what to plant in its stead.

Water Delivery / Infrastructure improvements

The garden uses municipal water ultimately sourced from Mokelumne River in the central Sierra Nevada. The garden’s aging system of galvanized pipes in shifting soils has been gradually mapped, more efficient irrigation heads installed, and leaks repaired. The UC Berkeley Campus administration is now funding an upgrade of the irrigation system. The replacement materials are easy to repair, a consideration in shifting soils. Part one of this upgrade has been completed with the installation of a timer to allow water to be applied in pulses, ensuring infiltration and minimizing run-off.

Expanding Water Storage Capacity

The Gardens is on potable water, although there is discussion of utilizing disused storage tanks located above the garden for a backup water supply. Otherwise there is neither the funding, nor the space to store an appreciable amount of water on the site.

Water Supply Policy

There is currently no memorandum in place to ensure the Garden receives priority when Campus is allocating water resources, particularly when water restrictions are in place. Negotiating with Campus Administration to ensure the living collection is seen as a museum collection rather than an ornamental landscape is an important step in ensuring continued supply of water for the garden should there be an emergency.

Risk Assessments of the likelihood and causes of water shortage

A risk analysis was undertaken as the first step in drawing up an emergency management plan. The loss of water as a result of landslide or earthquake was considered as a real threat to the collection. Both cases would potentially result in the water being shut off for an unknown period, depending on the extent of the damage. Wildfire is considered a major threat to the collection; in the event there would likely be no time to remove plants to safer locations.

The Living Collections Policy includes a section on risk management; with proposals on how to value the living collection in the event of loss for the insurance purposes. The cost of re-collecting accessions is acknowledged as a big expense, particularly if they where to be physically recollected from the wild. Managing fire, frost, and loss of glasshouse heat are addressed in the living collection policy, with a procedure around water shortage yet to be finalized (University of California Botanical Garden at Berkeley 2013)

How and Why Planning was Undertaken

The risk of water shortage, and the impact on the collection was identified as an issue by senior Gardens staff. The Horticultural senior staff worked with the Curator to identify and agree upon priority plants in the collection. The Campus Office of Emergency Management does not yet have a plan for the garden in the event of catastrophic water failure, however, the Gardens is working with them to determine how best to protect the collection.

Advice and reflection

Carmichael's advice is to put the energy into thinking about managing water shortage and other risks sooner rather than later. The fact that the garden is in a wildfire zone, in an active earthquake area, and has regular droughts is very challenging in terms of being on top of risk management.

> We all know this when it comes to any sort of disaster planning that being proactive is better than just waiting for it to happen but it's very hard in a lot of settings where we're so stressed all the time we are so understaffed and our resources are so limited it's very hard to make the time to do this sort of planning and in California, given the reality of our already intensive seasonal distribution of rain water, and the threat of drought that is unlikely to be expunged even if we have a good El Nino year, you can only grapple with it when you can grapple with it. (Chris Carmichael)

Carmichael recommends taking advantage of funding when it is available, because it may not be offered again. A regret expressed was that a project bid was not submitted ‘years ago’ when Campus may have had more money to spend on infrastructure upgrades.

Finally, Chris Carmichael says to consider the cost of not doing anything; to replace the Berkeley living collection would simply not be possible, given the embedded value of acquiring and maintaining it.

VIZCAYA MUSEUM AND GARDENS, MIAMI FLORIDA

A telephone interview was held January 8, 2016, with Ian Simpkins, Deputy Director of Horticulture and Urban Agriculture, Vizcaya Museum and Gardens, Miami, Florida. Follow up email clarifications were also made.

Miami has a tropical monsoon climate (Kottek et al. 2006) with annual average rainfall of more than sixty-one inches (1550 mm). It is somewhat cooler in winter than summer, and light frost can be experienced, although rarely (National Weather Service 2016). Table 5.5 details the climate statistics for Miami. Natural disasters experienced in Miami include hurricanes and tropical storms, tornado, flooding and drought (Miami-Dade County 2013).

Table 5.5 Climate data for Miami, Florida. Source: National Weather Service (2016)

Climate Averages –Miami Fl.		
Average maximum summer temperature (July & Aug)	32.8^0 C	91^0 F
Average minimum summer temperature	25^0 C	77^0 F
Highest recorded temperature (July)	37.8^0 C	100^0 F
Average maximum winter temperature (January)	24.4^0 C	76^0 F
Average minimum winter temperature	15.6^0 C	60^0 F
Lowest recorded temperature	-2.7^0 C	27^0 F
Average annual rainfall mm	1572 mm	61.9"
Average annual rainfall wet season months (May, Jun, Jul, Aug, Sept, Oct)	1184 mm	46.6"
Average annual rainfall dry season months (Nov, Dec, Jan, Feb, Mar, Apr)	389 mm	15.3"

Ten category three or greater hurricanes have impacted southeast Florida since 1990, the most damaging being Hurricanes Andrew in 1992 and Wilma in 2005. Damages of $25 billion were attributed to the category five Hurricane Andrew, the eye of which hit Miami-Dade County about 25 miles south of the center of Miami. A storm surge of 4 to 6 feet occurred at the northern end of the Bay of Biscayne, where Vizcaya is located. The storm surge towards the center of the Bay was up to 16 feet (Ed Rappaport National Hurricane Center 1998).

Notwithstanding the high average annual rainfall figures, Florida has experienced eleven severe droughts in the past 100 years (Florida State Climate Center 2016). Miami's potable water, and most of its irrigation water, comes from the surficial limestone Biscayne Aquifer (Figure 5.7).

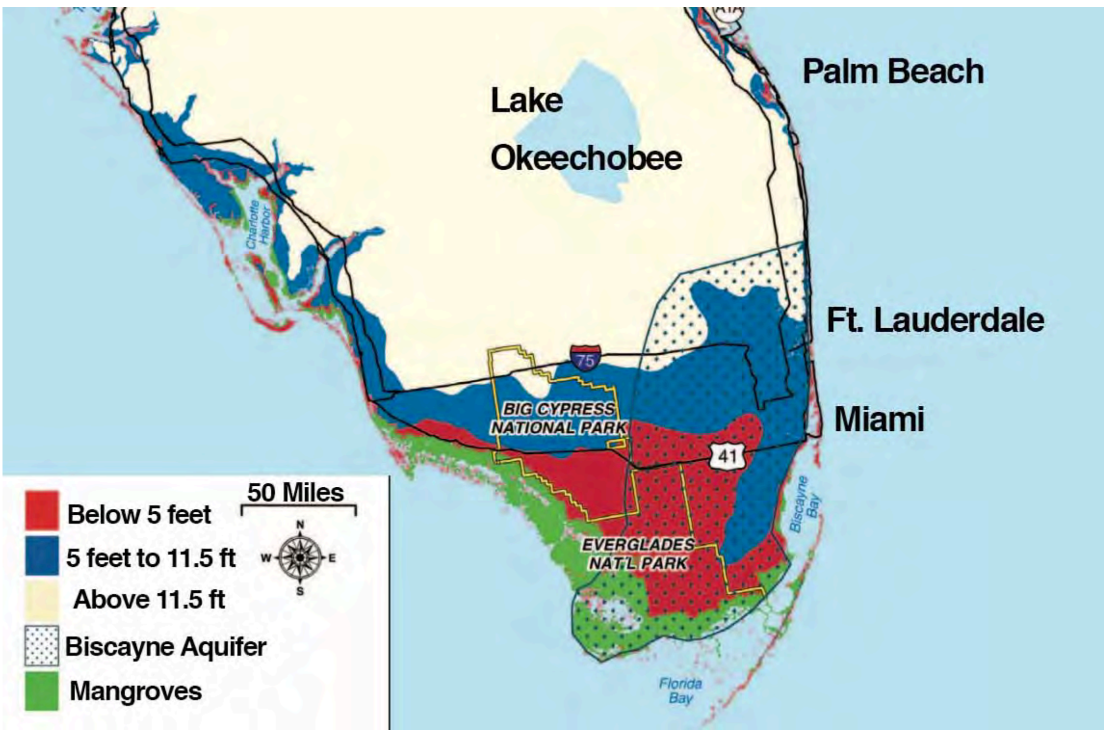


Figure 5.7 Elevation of southern Florida, showing the Biscayne Aquifer (dotted). Source: EPA (2002)

The Biscayne aquifer is subject to saltwater intrusion, originally associated with the draining of the Everglades, and more recently with over-extraction and drought. The region has low relief and low altitude, with 70% of Miami-Dade County below 6 feet (1.8 meters) above sea level. The region is facing water shortages; as climate change induced sea level rises exacerbate the level of saltwater intrusion into the aquifer (Prinos et al. 2014), and the demand for water increases with population growth. In addition to freshwater shortages, flooding after heavy rainfall is also a problem, again due to the low altitude of much of the region.

Vizcaya Museum and Gardens is a 50-acre (20.2Ha) estate on Miami's Biscayne Bay waterfront. Mr. James Deering, Vice President of the International Harvester Company, constructed the estate in the early 20th century. In 1952, Vizcaya was conveyed to Dade County (now Miami-Dade). During construction of the estate, Deering conserved a very significant remnant Rockland Hammock tropical hardwood forest; a closed forest that grows on shallow soils with underlying limestone (Florida Natural Areas Inventory 2010). This 25-acre (10 Ha) forest now represents one of the few areas of forest in Miami. The estate also has ten acres of formal gardens (Figure 5.8), and more than 2,000 orchids. Significant plants include 100 year old Cuban royal palms, *Roystonia regia*, and live oaks (*Quercus virginiana*) transplanted as mature specimens at the beginning of the 20^{th} century from other Deering properties. Mangroves still line the south eastern shore of the estate.

Vizcaya supports climate change action, in particular local responses to ameliorate the impact of this global problem. The organization is conscious of being good environmental stewards, partnering with Florida's CLEO Institute (Climate Leadership Engagement Opportunities) to develop its climate change statement and action statement. Vizcaya was recently the recipient of $50 million funding from the County and benefactors, with garden and irrigation restoration costing around $7.5

million. Planning for restoration of the garden is under way, with works being guided by a cultural landscape report documenting the garden's history.

Figure 5.8 Vizcaya Museum and Gardens' formal gardens of hedges and lawn. Image: Fran Jackson

Planning Elements

Horticultural/Operational

The soils at Vizcaya are "terrible", according to Ian Simpkins. They consist of either marle (decayed limestone) or sand, and are very porous and nutrient poor. Previously, nothing was mulched in the garden, now the garden makes its own mulch and other organic material to improve water holding capacity and slow evaporation.

The garden has reduced its use of fertilizer and chemicals; cognizant that run-off is directly into Biscayne Bay. This, in turn has influenced plant choices, material that needs less water and fertilizer being preferred.

Collections

Vizcaya must deal with a range of challenging questions around its collections. The goal is to have a horticulturally significant garden, using plants rare in cultivation, as well as rare and endangered plants to promote their use in the landscape. A living collection plan is in development. The absence of a County approved collections plan is hindering the ability to move forward with collections revision and planning, and because of the delay in approving the living collection plan, at this stage no criteria have been set for evaluating collections for future suitability. The focus is on preserving historic germplasm, and using native material that is well adapted to the climate.

Water Delivery / Infrastructure improvements

A new automated and low flow irrigation system is slated for installation as part of the upgrades to fountains and watering systems.

Expanding Water Storage Capacity

Medium term planning has restoration of the historic garden infrastructure, including the fountains as a priority. This work also entails upgrading stormwater management, which will be collected and directed into a cistern, filtered, then injected into the aquifer. The plan is to run this water through the fountains prior to using it for irrigation. Aquifer injection is a strategy used to help hold back saline water intrusion into the aquifer; Vizcaya is on the 'wrong side' of the salt line, the line that demarcates saltwater interface with the freshwater aquifer (Prinos et al. 2014).

Water Supply Policy

The South Florida Water Management District ('the District') is the authority overseeing the complex supply system supplying water to 8.1 million residents of Florida's sixteen southern counties, including Miami-Dade County. The District offers funding to private and public organizations and homeowners for alternative water supply or stormwater management projects. Furthermore, by the end of 2015 the Florida Department of Environmental Protection was legislatively required to examine ways to expand the use of reclaimed water, including stormwater. Research into aquifer storage and recovery techniques that recycle treated water back into the Biscayne Aquifer under the Everglades and other natural areas is ongoing. The technology is currently used in the Floridian Aquifer to displace brackish water (South Florida Water Management District 2016). Vizcaya proposes to use a deep well injection technique to store stormwater and slow the halt of saltwater intrusion into the Biscayne Aquifer.

Risk Assessments of the likelihood and causes of water shortage

A formal risk analysis was not undertaken, however staff at Vizcaya consider climate change as a likely driver of water shortage, through sea level rise exacerbating saltwater intrusion into the Biscayne aquifer, in addition to the predicted increase in temperatures, and more variable rainfall patterns. The 2009 drought was a catalyst for the organization to consider how it could best respond to water shortage. During that drought, the remnant Rockland Hammock forest had dried out to the extent that it needed to be watered weekly to prevent fires from igniting, either through vandalism or accidentally, and a great deal of water was used to ensure not only was the garden kept alive, but it also didn't catch fire.

Ian Simpkins reports that another issue is changes to the wet season, that the rainy season appears to be starting later, depriving the garden of rainfall when it is needed during the hot months of May and June, at the time when the aquifer draw-down is at its yearly peak. Misra and DiNapoli (2012) report the start date, finish date and length of the annual wet season can vary from the mean by a month or more; recent late commencement is likely connected with drought conditions. Changing climate, including warmer winters, urban heat island effect, and warmer nighttime temperatures are affecting what can be grown at Vizcaya. For instance, Simpkins reports that lychee no longer reliably fruits at Vizcaya due to warmer overnight temperatures; he says 100 years ago, nighttime temperatures above 70^0F (21 deg C) occurred on average for two months of the year, now these warmer nights are occurring for five months.

The Planning Process

Senior staff from Vizcaya worked together on a strategic plan for the organization. Taskforces were formed, including an Interpretive Planning Taskforce to develop the public messages and statements around Vizcaya's master planning and environmental initiatives; and the Preservation and Maintenance Taskforce, whose role is to develop implementation strategies for restoration and maintenance of the house and garden. Miami-Dade County is part of the South East Florida Regional Climate Compact; this includes regional and local governments, and the South Florida

Water Management District and is tasked with managing the effects of sea level rise and climate change impacts.

Advice and reflection

Ian Simpkins' advice is to start planning early for climate change impacts, and don't get caught with aging and failing infrastructure. Vizcaya is dealing with an antiquated irrigation system, and fountains with 100 year old plumbing that leak "everywhere", with work not due to start on restoration for several years. His other advice is to look at what can be improved without major capital expenditure, and investigate how to become more efficient stewards within the existing structure.

A Florida Public Garden

Telephone interview, February 10, 2016, held with a garden in Florida that chose to remain anonymous.

Planning Elements

Horticultural/Operational

Many trees and palms do not need supplementary watering in the Florida climate, however the display gardens are watered regularly to keep the turf green year-round. Other collections are watered for frost protection in the event frost is forecast, but generally do not need supplementary irrigation.

Collections

The respondent observes that in a general sense, collections having no clear objectives or purpose are difficult to assess and prioritize because their role in the collection is not defined. It is also noted the living collection policy will be updated in due course to ensure the collection reflects the contemporary goals and objectives of the organization. Lower sections of the garden have habitat plantings adapted to occasional inundation by salt water from king tides. Some collections have been shared with other gardens and individuals to manage the risk of loss to drought, hurricane or pests.

Water Delivery / Infrastructure improvements

Water for the botanic garden is supplied from onsite wells, with reverse osmosis ('RO') units to manage saltwater intrusion from the aquifer. Reverse osmosis uses a lot more well water than the output of fresh water, and as such is not particularly sustainable in terms of water rejected. The garden well also has hydrogen sulfide contamination, which needs management to ensure it doesn't contaminate fisheries due to low oxygen levels. The irrigation systems can be run on evapotranspiration models, but are usually run twice per week in the main garden as a matter of course so that turf is maintained. Irrigation can be backed off in the event of water shortage, the turf would suffer but generally the collections would cope, reports the respondent.

Expanding Water Storage Capacity

A cistern in the nursery captures rainwater from the nursery buildings. The respondent suggests more cisterns to capture rainwater rather than using the resource intensive reverse osmosis would be an elegant solution, but thus far there is no budget for this work.

Water Supply Policy

The respondent reports there is little or no contact with the water authority, as the garden's water is drawn from the aquifer, but it is still subject to restrictions on use in the event of water shortage.

Risk Assessments of the likelihood and causes of water shortage

Preparation and planning for water shortage seems to be predicated on having the capacity to desalinate the water supply, and supplying water from a mobile water tank. Rising sea levels will impact some of the garden initially, ultimately inundating all of it.

Advice and reflection

Ensure there is a clearly articulated purpose for each of the living collections; this would help enormously when assessing and prioritizing collections. Building rainwater capture and storage would help alleviate the demand for desalinated water. Consider whether collections need watering for plant health, and if watering may be reduced without loss of amenity. Turf, for example, may manage with less watering, albeit not quite so green during the drier months.

OTHER GARDENS INTERVIEWED

BLUE MOUNTAINS BOTANIC GARDEN, MT TOMAH, N.S.W. AUSTRALIA

The Blue Mountains Botanic Gardens, a cooler climate garden, part of Sydney's RBG and Domain Trust, is located between the Blue Mountains National Park and Wollemi National Park, a place that experiences occasional intense and catastrophic bushfires. The garden is not on municipal water, capturing and storing rainwater in a dam approximately 15ML (12.2 acre-feet) in capacity. An issue for the garden is when, during bushfires, water bombing helicopters and trucks extracting up to 6KL of water from the dam at a time, much of this water being used to protect the botanic garden and nearby properties. During an intense bushfire in October 2013, water was being taken from the dam at an alarming rate; raising concerns the garden would not have sufficient water to last through the summer (Greg Bourke. 2015, Pers. Comm.). This episode highlighted the importance of not only having a backup plan for the water supply, but also a plan for the collections to safeguard it against loss and disaster.

Bourke also notes that the increased evapotranspiration impacts of climate change is increasing the demand for water, while at the same time reducing the amount of water available for irrigation. The gardens' risk analysis matrix was updated to include possible threats to the water supply, including from drought, bushfire, vandalism or dam failure. Actions arising from the risk analysis included:

- Duplicating valuable collections and growing them at other botanic gardens, or at least storing them in the nursery.
- Prioritizing the construction of a second water storage dam in future capital works budget bids,
- Installing a gray water irrigation system as part of facility upgrades
- Locating a source of suitable bulk water for short term use should trucking water in be required
- Prioritizing which collections will be watered in the event of water rationing

The major areas of concern in the event of water shortages are the loss of amenity in the gardens overall, and the loss of rare accessions. The collection was prioritized according to conservation value; firstly how rare they are on a global scale, then how common they are in collections, then whether it is wild-sourced. If accessions are sufficiently valuable based on this criteria they would be vegetatively propagated and shared with other Australian botanic gardens. One issue that became apparent very quickly was that few botanic gardens have collections or climate similar to Mt Tomah, and that curation priorities may not be the same at other gardens. Bourke says one of the challenges to this work was bringing the collections data up to date, and identifying some unidentified trees. The staff are not always aware of what accessions are really significant; therefore, producing a one-page location map and list of these plants is one of the curation goals.

The garden has installed water meters within the garden to monitor water use and gain some insight into water use patterns. The dam level is monitored, with plans being drawn up to withdraw watering, if the need arises, from sacrificial areas (in particular turf). Bringing the disparate parts of the plan together into one document, and completing outstanding tasks is a short-term goal; for instance, ensuring a communications plan with the National Parks Service and Rural Fire Service is articulated, securing an agreement for an alternative supply of bulk water in the event the dam fails, securing appropriate alternative locations for vegetatively propagated plant material, and updating and validating the living collection data. A review of the living collections is also slated, the current planning is based on the existing collection, but Bourke anticipates that climate change projections may change the composite of the collections in the longer-term (figure 5.9).

When asked if he would do things differently, Bourke recommends having someone dedicated to the task of putting the plan together, ensuring there are people and resources directed to the process, and involve other institutions and peers early on to ensure effort is not duplicated. Additionally, if resources were no object; have someone dedicated just to updating the plant records data, ensuring plants most in need of preservation can be readily identified and targeted for action.

Figure 5.9 The Blue Mountains Botanic Garden sits atop Mt Tomah, currently cool climate, but projected to become warmer with climate change. Photo credit: (Hanuska 2011)

WOLLONGONG BOTANIC GARDEN, WOLLONGONG, NEW SOUTH WALES, AUSTRALIA

Wollongong Botanic Garden's Curator, Paul Tracey was interviewed at the garden in October 2015. The garden is owned and managed by the City of Wollongong, and features collections of palms and local and western Pacific sub-tropical rainforest plants. It also holds other collections, including *Camellia* and the

Towri Bush Tucker Garden, and a xerophyte garden (figure 5.10). The garden had to contend with level 3 water restrictions during the Millennium drought (garden watering limited only to hand watering, twice weekly before 10am); and notwithstanding a mean annual rainfall of 1350mm (53"), drought is an expected and episodic part of the Wollongong climate.

Figure 5.10 Wollongong Botanic Garden's xerophyte garden, built up to prevent waterlogging in wet years. Source: Wollongong Botanic Garden. Photo: Fran Jackson

More recently, money, rather than drought prompted Wollongong to examine its water use. In the past five years, water bills were double, or in some years, triple the $46,000 annual water budget. Overspending on water was impacting on other operations in the garden, with materials, staff hours and projects foregone to accommodate the increase in water cost. To manage its water budget, the garden has been assessing its collection to determine what is significant, what can be removed, and what can be changed. The former huge garden beds have been progressively reduced in size; compressing the beds has helped reduce water use, without impacting on the amenity of the garden. Other beds, including annual displays, have been removed to enable water resources to be directed to higher priority beds, including the twenty-two species of IUCN listed critically endangered palms.

> The decision moving forward to look at water prioritization on our collections was based purely on it we can't spend it we can't grow it, so if drought comes again we're going to have to make tough decisions. (Paul Tracey)

An issue for the garden is maintaining its visitor appeal while cutting back on display beds, for instance, the removal of the water intensive annual display beds prompted considerable negative feedback from visitors, 70% of whom are from the Wollongong region. Many of the horticultural staff have been at the gardens for decades, and implementing changes to the collections and displays is difficult.

> There's a lot of emotional ties to the garden. So every change is a challenge, every living collection for staff is hugely important… (Paul Tracey)

The process of prioritizing collections and assessing what material is appropriate and less water needy is ongoing; regionally endemic rare and endangered material may not need as much water as exotic collections for example. The focus is on the quality of the displays, rather then the quantity, and interpretation for displays has improved. The garden has formed a partnership with four other botanic gardens in southeastern N.S.W. and the A.C.T., including the ANBG. This has enabled collections priorities to be set on a regional level, joint collecting trips to be undertaken, and streamlining tasks such as accessioning of herbarium vouchers.

In addition to rationalization of its collections, a capital bid was lodged with Council to upgrade the irrigation to an automatic system, and to expand the current water harvesting and reuse system.

> I've got a team of 12 horticulturists standing on the end of hoses, how can I offset those costs, as well as the overruns on the cost of the irrigation water? Basically it's just common sense for us. (Paul Tracey)

When asked what would he do if the garden had sufficient resources, Tracey identified completing a new landscape master plan, and project plans and funding for infrastructure, including the irrigation system as priorities. He also notes that community and Council sentiment could disrupt the garden's plans for prioritizing watering of collections based on their assessed significance.

> The challenge for me is that you work in a reactive organization, it reacts to issues. You're on a site with a lot of history where you need to react to current day conditions. I fear that even though we've done this work already on prioritizing water management for collections we're not in a position to where we have to respond to that. That's the balance point that I'm not sure of yet. We've built this garden on the basis on it being community friendly, so to turn around and say we're not going to water the turf if we get a severe drought, I don't think it's going to sit well.

ADELAIDE BOTANIC GARDEN

Andrew Carrick, Manager, Collections and Horticulture at Botanic Gardens of South Australia, interviewed via emailed questions in November 2016.

Adelaide Botanic Gardens (ABG) and the adjacent Botanic Park together encompass 51 hectares on the edge of the City of Adelaide. The garden has recently completely an $8.7 million wetland project, jointly funded by the Australian Government, the South Australian Government, and the Adelaide and Mt Lofty Ranges Natural Resource Management Board. The First Creek Wetlands Project is expected to eventually capture and store up to 100 ML (81 acre-feet) of water each year, using managed aquifer recharge and surface storage. The wetland is designed to ameliorate the regular flooding experienced from the urbanized First Creek and Botanic Creeks, and to 'drought proof' the Adelaide Botanic Gardens. With a mean annual rainfall of 546mm (21.5") (Australian Bureau of Meteorology 2016e), Adelaide was on increasingly more stringent water restrictions for seven years during the Millennium drought, and now has 'Water Wise Measures', a form of permanent restriction which, among other things, prohibits irrigation system and sprinkler use between 10am and 5pm.

The wetlands project came about after a waterways study completed in 2003 to address issues with flooding and water shortage at the garden. The Botanic Gardens Waterways Study (Ecological Engineering 2003) was then incorporated into the new Master Plan for Adelaide and Mt Lofty Botanic Garden (Taylor Cullity Lethlean 2006). The award winning two-hectare wetland and visitor interpretation and viewing area was completed in 2013 (figure 5.11).

Figure 5.11 First Creek Wetland at the Adelaide Botanic Gardens. Source: ABC News

At the same time as this major project was being incubated, other work was occurring to address living collections security in the face of water shortage. Curators and horticulturists reviewed and prioritized the living collections, building on the Master Plan's 'focus collections' and seven thematic areas. A priority of the living collection review was preserving and stabilizing the mature tree collection in the ABG and Botanic Park. Other recent and proposed developments are now designed with water conservation as a key design criterion. SA Water partners with the garden to promote water-wise gardening. SA Water was a major sponsor of the Mediterranean Garden, constructed to showcase low-water use plants. SA Water also contributed $100,000 towards planning the irrigation system upgrade, with capital funding of

$800,000 from the SA Government provided to carry out the work. The irrigation system is now fully automated, with schedules based on real-time weather conditions, but the garden does not have full irrigation coverage as yet. Carrick notes that one of the challenges in assessing and prioritizing important components of the collection, and de-accessioning parts of it deemed no longer relevant was

> Managing the emotional attachment to collections. Each staff member has their favorite, but all were assessed historical and cultural, ornamental and landscape values and prioritized from there. (Andrew Carrick)

The garden prioritizes watering, with some areas of turf allowed to brown off, the decision as to which areas based on turf with inefficient manually shifted sprinklers has low priority. Trees are given additional water.

CURLEWIS GOLF CLUB AND PENNANT HILLS GOLF CLUB

This research has been confined in the main to botanic gardens, however, looking further afield, it is relevant to mention the examples of two Australian golf courses. Curlewis Golf Club, located in Victoria, had its potable water dramatically reduced when severe water restrictions were introduced during the Millennium drought. The condition of the golf course declined to the extent that membership numbers fell by more than a third. The Club installed a sewer mining plant, tapping into a sewer main located on the boundary of the golf course. The project cost around $2 million, with an additional $60,000 per year in operating cost. The project uses Membrane Bioreactor technology (MBR), with rejected sludge going back into the sewer (Clearwater 2016). The scheme produces 60 ML (49 acre-feet) of Class B (water suitable for some irrigation purposes) per year, however with further treatment using reverse osmosis and disinfection, the process is capable of producing Class A (water suitable for non-potable urban purposes) water if required. Pennant Hills Golf Club in Sydney installed a similar system at a cost of $3.5 million (Water Environment and Reuse Foundation 2016). Several other Australian golf courses, including Sunshine Golf Club in Victoria (City West Water 2016), have also installed these systems. Golf courses can manage better the impact of soil salinity build-up from using recycled water, as they grow one ‘crop’ (turf). However, it is worth noting the technology is available to utilize a local source of water that is currently not limited except by the capacity of the treatment plant.

Chapter 6

RECOMENDATIONS

LIMITATIONS OF THIS RESEARCH AND RECOMMENDATIONS FOR FUTURE RESEARCH

This research reflects the survey and interview data obtained, however it should be noted that after several requests to do so, a large majority of public gardens in the United States did not respond to the survey, while only about half of Australian gardens sent the survey completed the questionnaire. The criteria for selection of gardens interviews was based on the answers to the survey questions, it is therefore entirely possible that important initiatives have not been captured in this research.

Answers to some survey questionnaire were not always an accurate reflection of a garden's situation. For instance, several gardens shortlisted to be interviewed did not have plans to manage water shortage, although they had indicated differently in the survey. Given the limitations of the survey and the low response rate, it is recommended that a more targeted approach be taken in future research in this area. For example, this research showed that those gardens located in climatically benign areas of the north-east and Great Lakes region of the United States do not have issues with water shortage. Targeting gardens in the south, west and central areas of the United States where the experience of episodes of drought is common may reveal more insights into managing water shortage. Initially, it is recommended that senior staff be contacted directly, either by phone or email, to ensure the most appropriate person in the organization is the key contact person. In the United States, it is also recommended that assistance and cooperation be sought from the Directors of Large Gardens group.

Future research in this area may include revisiting those gardens profiled in this research to monitor the success or otherwise of their plans to manage living collections in the face of water shortage. As gardens become better prepared for climate variability, targeting future research to those gardens in more variable climates would probably yield further insights in this area.

LIVING COLLECTIONS MANAGEMENT IN THE EVENT OF WATER SHORTAGE

This guide to managing living collections in the event of water shortage synthesizes the practices and experiences of United States and Australian gardens, and other institutions that examined in this research, and can be summarized thus:

- Assess the risk to the collection from water shortage
- Review the collections
- Review the water supply
- Review the horticultural practices
- Prepare a realistic budget
- Manage stakeholder expectations
- Review periodically
- Consult experts inside the organization and externally
- Gain commitment from the whole organization
- Implement in stages

Risk Assessment

Undertake a risk assessment of the impact of a long-term (more than one month) loss or reduction of water supply. Connect and consult with local expertise and stakeholders, for example, the local water authority, regional climate scientists, and other institutions facing similar issues. While this plan is focusing on longer-term water shortage, consider also the impact of an unforeseen short-term loss of water, such as a water main breakage. Both scenarios require preparing a plan in advance, and establishing contacts and expertise that can provide assistance in an emergency. The lessens from one risk assessment can inform the other. Use a risk matrix to assess the likelihood and the consequences of water shortage. Consider undertaking a cost benefit analysis and assess the cost of doing nothing compared with taking action. If the risk of water shortage is deemed unacceptable, develop a strategic plan to manage water shortage.

Environmental scan:

- Have there been previous episodes of water shortage?
- Do climate change forecasts indicate hotter, drier conditions?
- Is the living collection suited to future hotter, drier conditions?
- Will demand for water increase in the region? Will this affect the cost of water? Will there be sufficient supply to meet demand? How is the regional water management authority addressing future shortage?
- Will more demand be placed on the water supply for bushfire or wildfire suppression in the future?
- Will the water supply remain viable? Is there a risk of salinization?
- Will the living collection handle drought conditions without supplementary water?

Assess the potential consequences of water shortage. Consider:

- Death of living collections
- Loss of irreplaceable taxa
- Professional reputational damage, particularly if important collections are lost
- Institutional reputation damaged, and potential loss of donor and grant funding
- Loss of revenue from visitors, venue hire
- Poor staff moral
- Expense incurred removing dead plants
- Loss of collections from bushfire or wildfire if insufficient water for fire suppression
- Expense incurred to acquire replacement collections and extra maintenance costs.
- Long-term changes to micro-climates associated with loss of vegetation cover

Prepare a Plan to Manage Water Shortage

Good corporate governance practice dictates that if the risk to the living collection from water shortage is unacceptable, a plan should be prepared to reduce the impact. Appoint someone within the organization who will take carriage of the plan, who will promote it to stakeholders, and whose enthusiasm for the subject is genuine, as they could be working on it for quite some time. This research has shown that gardens most prepared for water shortage have a 'champion' within the organization driving innovation and persisting in the face of challenges.

In preparing a plan to manage the risk to the living collection from water shortage, some assumptions may be made based on previous experience of water shortage in the area, and possible future scenarios. There is no exact way of predicting how long a water shortage episode will last, however, as an example, if the previous worst drought on record lasted for two years, and rainfall was reduced by 50% over that time, this would be a base line to use for planning purposes. If climate change forecasts include hotter and drier conditions, add a margin of error to account for this. For instance, the previous base line two years and 50% less rainfall might be extended to three years, to factor in the influence of climate change. Ideally the worst case scenario will never eventuate, however as the United States and Australian experience of record breaking drought in recent times has indicted, the worst case is now just a new benchmark.

During the planning process, do not automatically exclude otherwise effective projects that are expensive to implement. If they are part of a strategic plan to manage water shortage, funding may be justified and found, but on a longer time frame, or the projects may be broken down into smaller developments. The experience of gardens has shown that what may have appeared a fanciful ambition twenty years ago is now a fully funded project. Government grant funding may be available to partially fund projects, particularly where implementing and testing new technology forms part of the scheme, as was the case with Adelaide Botanic Garden's wetland and aquifer storage project.

Consider the following actionable areas in the plan.

Collection:

- Is there sufficient knowledge of the important components of the collection? Is information about conservation collections, heritage collections, and rare plants current? Build consensus from horticulturists, curator/s, and researchers to develop criteria to prioritize collections. Seek advice from BGCI, APGA or BGANZ to connect with other institutions with similar collections. Upload the garden's plant list to BGCI's PlantSearch database to ascertain the conservation value of the collection and conduct a names audit (BGCI 2016) if required.

- Assess the suitability of the collection to adapt to future climate and water regime. Is the current collection appropriate? Is it possible to replace high water demand material with lower water requirement?

- Document important material. Assess need and suitability for duplication and exchange with other institutions. Not all material will be suitable, and not all significant collections will be / should be duplicated as insurance. Ensure proper documentation of material sent to other institutions so that people and the institution know where it is.

- Identify sacrificial material – those plants that will be watered after high-priority plants, or not at all. Is this material readily available and easy to replace?

- If the garden cannot save everything, at least it can decide what to prioritize, and demonstrate good governance of the collection.

- Continue to group plants with similar water needs together to maximize watering efficiency, and ensure this happens with new developments.

Horticulture:

- Use mulch to slow evaporation. Locate suppliers of suitable mulches ahead of time. Decide which one to use based on local availability and with reference to Chalker-Scott's (2007) review of suitable mulch types and application depths. If possible ensure mulch is down before drying commences.

- Cease ordering or planting new material, particularly annuals, or at least substitute low water requirement plants if the garden will suffer economic loss from lack of seasonal displays. Consolidate plants in the institution's nursery if possible to reduce water requirements.

- Consider shipping valuable potted material to another place not affected by water shortage. Be prepared; negotiate potential locations in advance of water shortage. Ensure good documentation of the loan.

- Time the watering to ensure the least amount of evaporation; water in the early morning, late afternoon, or overnight if there is an automated system.

- Use soil moisture monitors and water more deeply, less frequently.

- Remove plants of little value to free up staff and water resources to focus on more important collections.

Water:

- Based on current use patterns, calculate how much water will need to be sourced, or how much will need to be saved in the event of water shortage. The assistance of local agricultural or horticultural extension services or irrigation consultants might be helpful. Managing the water deficit is what the plan is constructed around.

- Assess options for water supply. What is the likelihood of water supplies being reduced or restricted during drought or natural disasters such as earthquake?

- Will reducing water consumption in non-drought periods help manage water shortage? For instance, if the institution currently pays a volumetric water charge, can water consumption be reduced and the financial savings used to pay for excess water during drought? Will the water authority look favorably on efforts to use water more efficiently? Can stored water be used more efficiently to ensure there is more available in the event of a drought?

- Know the gardens' water use. If not known, consider installing meters to monitor daily use patterns and to detect leaks. Are there any obvious savings that can be made? For example, can leaks be repaired? Capture, store and distribute water as efficiently as possible.

- Audit the irrigation system. Address any deficiencies in water delivery before water shortage strikes. Does the irrigation system need repairing or upgrading? Does it have the capacity to be used manually, and can certain watering zones to be overridden? Are the irrigation heads delivering water efficiently? Are there leaks, areas of overwatering or issues with run-off from impermeable soil? Assess the capacity of staff to carry out this audit and consider using a consultant if capacity is limited.

- Review watering schedules and application rates, including seasonal changes to ensure waster is being used as efficiently as possible and not lost to evaporation, run-off or below the root zone.

- Ensure staff professional development includes training in irrigation and water management.

- Is there an alternative source of water available to the garden? If no readily available alternative, is it feasible to access water from further away? Is using groundwater feasible?

- Is it feasible to construct water storage, to harvest and store water prior to a drought? How much onsite or near-site storage would be available for constructing cisterns, above ground tanks, lakes, or storage dams? Could it be shared with a neighbor? Can water be harvested externally to the garden, for example from local streets?

- Investigate whether topographic changes can be made to install swales and diversion banks to channel rainfall onto garden beds, provided waterlogging is not an issue.

- Can reverse osmosis be used to treat available brackish water? What about sewer mining? Can the gardens afford the capital cost and the operating cost?

- Undertake a cost benefit analysis of alternative water supply solutions, compare with the cost of potable water and include the economic cost to the gardens from drought and loss of collections.

- Engage with the water supplier early, before water shortage occurs. Educate the water supplier about the importance of the living collection, and the economic benefit it brings to the community.

Budget:

- Develop a capital expenditure program and if necessary, break down components of the program to enable funding and completion of smaller projects.

- Investigate grants and subsidies. For example, the Pennant Hills and Curlewis Golf Club sewer mining projects were both partially funded by State and Federal Government subsidies to provide proof of concept for the technology.

Public Relations:

- Managing stakeholder expectations is critical to the success of any plan to manage water shortage.
- Develop a public relations plan and implement it before water shortage occurs. Explain why the grass will be brown, and why it is important to keep supporting the institution even when it does not look its best.

Gaining the support and commitment of the whole organization is key to producing a sustainable plan to manage water shortage. Prioritizing budgets and human resources to manage water shortage needs the buy-in of internal and external stakeholders.

Lastly, document successes and things that did not work out as expected. Share the information with other institutions, and be prepared to adjust expectations.

Chapter 7

CONCLUSION

This research indicated there is essentially two ways to manage the threat of water shortage to living collections: manage the collection, or manage the water. The more comprehensive plans managed both. The research showed that if a garden had experienced water shortage in the past twenty years, it was more likely to have a plan to manage it. Conversely, a garden that had never experienced water shortage was less likely to have a plan to manage it. This applied to gardens in the United States and in Australia. Around one third of gardens in Australia and the United States have plans in place to manage the living collection in the face of disasters other than water shortage. Fewer than one third of all surveyed United States gardens has planning in place to manage water shortage, however the percentage with plans increased to two thirds for gardens located in climatically variable regions, such as south western United States. In Australia, with its variable climate, the number of gardens with plans is close to two thirds. The research indicates that the likelihood of having a plan to manage a disaster such as earthquake, flooding, hurricane or drought, is greater if the garden has already experienced such a disaster, or is located in a region prone to particular natural disasters.

Good corporate governance of botanic gardens should include undertaking a risk assessment of the likelihood and impact of water shortage. The risk of doing nothing may be acceptable after careful assessment of the likelihood and impact. The best predictor of whether a garden has a plan to manage water shortages is if they have experienced water restrictions in the past. The gardens that were better prepared for water shortage had not only experienced shortage before, but also had people in place that kept working towards having a water safety net, in some cases for many years. There is no ‘ideal’ single solution to managing water shortage; changes to collections management, horticultural practices, irrigation management, and water resource management are individually and collectively possible solutions. Incremental changes will make a difference, for example, upgrading parts of the irrigation system as budget allows. A barrier to creating a systematic plan, at least for gardens in regions that could benefit from having one, was the long-term strategic planning required to recognize the risk and address it.

> Short-term thinking keeps us focused on the immediate needs. Strategic plan is only five years out, and makes no mention of water issues. (A Director of Horticulture, United States)

Cost is cited as the other main barrier to developing a plan to manage water shortage, however, developing a plan ought not be an expensive exercise, but the implementation plan will requires a budget commitment, with staged implementation a way of managing resource constraints. Without undertaking the planning, including appraisal of alternative solutions, there is no way of knowing what resources will be required. It is critical to work with external stakeholders; consult water authorities, local and state government agencies, and research institutions, and consult widely during an environmental scan to ensure institutions faced with similar problems are contacted. ‘Everyone is dealing with the same issue in slightly different ways’ said one Director of Horticulture. Pool the knowledge for a better outcome.

The support of the whole institution is vital to ensure a viable plan is produced, and the importance of involving internal expertise should not be underestimated. The people ‘on the ground’, in horticulture and facilities management know more about the garden and its infrastructure than any outside consultant, and may already have thought of creative solutions to water management issues. One Director of Horticulture, when reflecting on the apparent success of a project said he wished that the grounds staff had been more involved, because the completed scheme ‘would have worked better’, and regretted that the project managers had neglected to consult more thoroughly and consistently with those stakeholders through the course of the project.

Ensure there is a living collections policy in place. The policy is a strategic plan for the living collection, and will help guide decisions about the collection before, during and after water shortage episodes. Know what is in the living collection. Good corporate governance would suggest that botanic gardens have up to date collections information, but this was shown to often not be the case in practice. Recognize that updating collections information will have budgetary implications and build this cost into any planning for water shortage.

The final piece of advice from several gardens is worth reiterating. Start thinking about how to manage water shortage now. Start the planning process now, even if there is no clear funding solution to implement the entire plan at once. The planning process itself will make clear what needs to be done, and will help set out a timeframe and budget priorities. Do not leave it until the next ‘worst drought on record’ strikes before taking action.

> I don’t want to be the one who’s brought up in 50 years time as someone who didn’t think about the future and left the current day Director with all the problems to sort out. I think this is a big part of our job, the responsibility to look that far forward, and think about the future of the gardens, and not just what happens day to day. (Chris Cole, Director, Melbourne Garden)

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Appendix A

INSTITUTIONAL REVIEW BOARD PERMISSIONS

University of Delaware Approval

Informed Consent forms:

- Australian National Botanic Garden
- Royal Botanic Gardens Victoria Melbourne Garden
- Royal Tasmanian Botanic Garden
- University of California Botanical Garden at Berkeley
- Vizcaya Museum and Garden
- Royal Botanic Gardens and Domain Trust Blue Mountains Botanic Garden
- Wollongong Botanic Garden
- Botanic Gardens of South Australia Adelaide Garden

RESEARCH OFFICE

210 Hullihen Hall
University of Delaware
Newark, Delaware 19716-1551
Ph: 302/831-2136
Fax: 302/831-2828

DATE:	July 28, 2015
TO:	Frances Jackson, MS
FROM:	University of Delaware IRB
STUDY TITLE:	[783255-1] What Botanic Gardens and Arboreta are doing to Manage the Risk to Their Living Collections Posed by Water Shortages.
SUBMISSION TYPE:	New Project
ACTION:	DETERMINATION OF EXEMPT STATUS
DECISION DATE:	July 28, 2015
REVIEW CATEGORY:	Exemption category # *(2)*

Thank you for your submission of New Project materials for this research study. The University of Delaware IRB has determined this project is EXEMPT FROM IRB REVIEW according to federal regulations.

We will put a copy of this correspondence on file in our office. Please remember to notify us if you make any substantial changes to the project.

If you have any questions, please contact Nicole Farnese-McFarlane at (302) 831-1119 or nicolefm@udel.edu. Please include your study title and reference number in all correspondence with this office.

WILL YOU RECEIVE ANY COMPENSATION FOR PARTICIPATION?

You will not receive any payment or compensation for participating in this study.

DO YOU HAVE TO TAKE PART IN THIS STUDY?

Taking part in this research study is entirely voluntary. You do not have to participate in this research. If you choose to take part, you have the right to stop at any time. If you decide not to participate or if you decide to stop taking part in the research at a later date, there will be no penalty or loss of benefits to which you are otherwise entitled. Your decision to stop participation, or not to participate, will not influence current or future relationships with the University of Delaware or Longwood Gardens.

WHO SHOULD YOU CALL IF YOU HAVE QUESTIONS OR CONCERNS?

If you have any questions about this study, please contact the Principal Investigator, Fran Jackson, at fjackson@udel.edu or Dr Brian Trader, Director, Longwood Graduate Program in Public Horticulture btrader@longwoodgardens.org

If you have any questions or concerns about your rights as a research participant, you may contact the University of Delaware Institutional Review Board at hsrb-research@udel.edu or (302) 831-2137.

Your signature on this form means that: 1) you are at least 18 years old; 2) you have read and understand the information given in this form; 3) you have asked any questions you have about the research and the questions have been answered to your satisfaction; and 4) you accept the terms in the form and volunteer to participate in the study. You will be given a copy of this form to keep.

David Taylor *National Botanic Gardens*	x	17/5/2016
Printed Name of Participant	Signature of Participant	Date
Fran Jackson		2/2/16
Person Obtaining Consent (PRINTED NAME)	Person Obtaining Consent (SIGNATURE)	Date

 Participant's Initials

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Dr Lucy A. Sutherland
Australian National Botanic Gardens

Printed Name of Participant — Signature of Participant — 17/05/20166

Fran Jackson
Person Obtaining Consent (PRINTED NAME) — Person Obtaining Consent (SIGNATURE) — 2/2/16 Date

Participant's Initials ____________

There are no costs associated with participating in this study other than your time.

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Chris Cole, Director RBG Victoria, Melbourne Gardens		26.11.15
Printed Name of Participant	Signature of Participant	Date
		20/11/15
Person Obtaining Consent (PRINTED NAME)	Person Obtaining Consent (SIGNATURE)	Date

Participant's Initials

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David Reid | Horticultural Coordinator
Royal Tasmanian Botanic Gardens
DAVID REID
Printed Name of Participant

x ____________
Signature of Participant

26/11/15
Date

Fran Jackson
Person Obtaining Consent
(PRINTED NAME)

____
Person Obtaining Consent
(SIGNATURE)

26/11/15
Date

Page 3 of 3

Participant's Initials ____________

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Chris Carmichael Ph.D. Associate Director, Collections and Horticulture
University of California Botanic Garden, Berkeley, CA

A.Christopher Carmichael	A.Christopher Carmichael	12-22-1
Printed Name of Participant	Signature of Participant	Date
Fran Jackson Person Obtaining Consent (PRINTED NAME)	Person Obtaining Consent (SIGNATURE)	12/19/15 Date

Page 3 of 3

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Ian Simpkins, Associate Director Horticulture and Urban Agriculture, Vizcaya Museum and Gardens

Ian Simpkins	x [signature]	05-05-2016
Printed Name of Participant	Signature of Participant	Date
Fran Jackson	[signature]	5/5/16
Person Obtaining Consent (PRINTED NAME)	Person Obtaining Consent (SIGNATURE)	Date

Participant's Initials IS

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Greg Bourke Curator/ Manager Blue Mountains Botanic Garden

______________	x______________	3/5/16
Printed Name of Participant	Signature of Participant	Date
Fran Jackson	______________	1/5/16
Person Obtaining Consent	Person Obtaining Consent	Date
(PRINTED NAME)	(SIGNATURE)	

Page 3 of 3

Participant's Initials ______________

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Paul Tracey Curator, Wollongong Botanic Gardens

Paul Tracey	x	2/5/
Printed Name of Participant	Signature of Participant	Date
Fran Jackson		31/5/16
Person Obtaining Consent (PRINTED NAME)	Person Obtaining Consent (SIGNATURE)	Date

Participant's Initials

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Andrew Carrick

Printed Name of Participant | Signature of Participant | 23/11/15 Date

10/11/15

Person Obtaining Consent (PRINTED NAME) | Person Obtaining Consent (SIGNATURE) | Date

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Participant's Initials

Appendix B

QUALTRICS SURVEY RESULTS

UNITED STATES SURVEY

Q1.1 - What is the approximate number of living accessions recorded in your plant database as growing in your garden? (i.e. not the total number of individual plants but the total number of accessions)

4912
10000
10170
10,000
3312
2,244
9090
4,500
10,000
21,727
2150
7,500 names (not synonyms) from a century of records but "live" field confirmation but ca 2,500 accessions (which can be single plants or groups, depending on taxon/situation)
10,162
4400
4,500
1,500
3,000 plus
6618
approximately 12,100
150
23,000
currently do not have a plant database

? we don't record by accessions at the present time.
7000
1,200
8,073
20,000
860
200
4000
800
2000
1325
6043
29990
987
11,862
Do not have accurate data base on our living collections. I'd guess several thousand permanent species but we use lots of seasonal plants that are not permanent.
8703
150 +
Two
1,300 (approximately)
5,000+ trees in hazard tree database, Display garden plants not accessioned.
4,500
800
47,183
1400

A complex question since many of the historic plants have not been accessioned. Of those accessioned since 1978, there are probably 5K.
4,500
200
13,943
1,000
8000
3500
4600
2317
7117
Don't know; I am in the process of locating old paper records and conducting re-inventory of collection
3000
2000
2697
8,902
17,000 accessions
6500
4,000
1200
14,000
1551
10460
1500
300
1500

2300
18,177
8,568
7000
3300
300
11000
2734
2500

Q1.2 - Does your garden's living collection include any of the following? Check all which apply

Answer	%	Count
Plants cultivated from the first plant collected to describe the species (i.e. the type specimen)	30.00%	27
Documented wild collected plants?	64.44%	58
Documented wild-collected IUCN Red-List plants?	26.67%	24
Rare cultivars?	70.00%	63
Plants that are difficult to replace due to restrictions on collecting new material?	46.67%	42
Plants that are expensive to replace?	78.89%	71
Heritage trees?	48.89%	44

Q1.3 - Are the important plants in your garden noted, either on a separate list, or flagged in the garden's plant record system? 'Important'' plants might include, for example, wild collected species, rare cultivars, heritage trees, plants cultivated from the first plant collected to describe that species (the 'type specimen') or plants that are otherwise significant to your garden.

Answer	%	Count
Yes	46.74%	43
No	53.26%	49
Total	100%	92

Q1.4 - Does your garden have a plan for managing or responding to natural disasters which may impact its living collections? As an example, a disaster management plan for the living collection might include management of cyclone and storm damage, floods, earthquakes, pest and disease outbreak, drought or extreme cold or heat.

Answer	%	Count
Yes	29.67%	27
No	70.33%	64
Total	100%	91

Q1.5 - Does the disaster management plan for the living collection include a strategy to manage water shortages?

Answer	%	Count
Yes	44.00%	11
No	56.00%	14
Total	100%	25

Q1.6 - Has your garden lost any important living collections due to drought or water restrictions in the past 20 years?

Answer	%	Count
Yes	31.11%	28
No	68.89%	62
Total	100%	90

Q1.7 - Please describe what collections were lost?

Numerous established trees, including several mature Quercus specimens have continued to deteriorate following a 2012 drought. Once collection to suffer particularly was the Ulmus collection, in which we suspect declining growth rates following the 2012 drought has made the collection more prone to Dutch Elm Disease. Several infected trees were removed in 2015.
A drought in 2012 resulted in setback of growth for many accessioned plants. Several mature oaks and trees of importance in the elm collection began to decline, likely resulting from this stressor.
Mainly Pines, some oaks, Willows,
A few heritage specimen trees (Sequoiadendron giganteum)
Mostly newly planted, unestablished trees and shrubs.
We lost heritage trees in our unirrigated natural areas.
The limiting factors that affect our ability adequately to water our mature collections during doughty conditions include staffing resources and accessible sources. When necessary, we irrigate the collections with large "water cannons" that are run off city fire hydrants. But not all areas have hydrants. Drought is one compiling factors that has led to decline of plants in our collections. When possible (time and money) we expand our irrigation infrastructure.
i'm not sure, just assuming since there was a severe drought here in 2007. I wasn't working here at the time nor did the garden have a plant recorder on staff.
Individual plants, typically within the first three years of planting do to drought.
Lost some species during severe dry spells but not many as we water intensely.

primarily azaleas, some younger trees
Plantings not yet established
Young trees lost to drought
Accessions in Magnolia, Cornus, Acer, Tilia, Rhododendron
Rhodies
BG-base does have a "Die Why" cause of death field that we, unfortunately, have not applied to our collections, so I can't provide a list of plants that have specifically died from drought/lack of water. However, aside from this summer (hottest and driest on record), most of our plant mortality due to drought/lack of water are newly transplanted core collections located in non-irrigated areas. Either they "fall through the cracks" and are not listed on our planting roster for the new plant care team to cover manual watering or they die from transplant shock/lack of water due to other stressors and abiotic site issues. We will definitely document drought killed plants for summer of 2015 though.
pines and oaks in areas without artificial irrigation and that depend on rainfall
Various decline trees have had their deaths accelerated by drought, thought drought was probably not the primary cause. Examples include camellias and fruit trees.
Certain garden areas were switched to reclaimed water. Over time our Sequoia sempervirens declined and died. Other plants in our Australian Garden also declined.
species rhododendrons
We have lost a few water stressed trees the last two summers. I don't know about earlier than that.
Some of the oaks and magnolia due to flooding. Some oaks and plant cultivars to drought and heat. Pine and surrounding plants due to lightning. Agave and Cacti several varieties damaged by flooding but most survived. The heat and drought has changed the garden in some areas to more sun and drought tolerant options either moving or removing several varieties.
Individual trees planted within the past 3 years. One Quercus palustrus and 2 Cercidiphyllum magnificum both in year 2.
Historic grove of Colorado blue spruce in Italian Gardens.

Q1.8 - Does your garden have a living collections management policy or purpose statement that describes what your garden collects and why?

Answer	%	Count
Yes	69.66%	62
No	30.34%	27
Total	100%	89

Q1.9 - Has your garden changed its living collections management policy / purpose statement in response to current or potential water shortages?

Answer	%	Count
Yes	4.55%	3
No	95.45%	63
Total	100%	66

Q1.10 - Please describe how your living collections management policy / purpose statement has changed in response to current or potential water shortages.

Our policy deals primarily with woody plants and we have a limit on the number of new installations that can be put in during a single year to manage the watering needs in the following years.   an unwritten policy has been to move many of the display garden areas from annuals to perennials and grasses to reduce the water demand.

Accepting no new accessions until drought is over, unless plants are water wise and need watering rarely or occasionally

Increased focus on Mexican collections and rare natives.

Q1.11 - Has your garden had water restrictions lasting for more than one month in the past 20 years?

Answer	%	Count
Yes - one time	10.23%	9
Yes, more than once - how many times approximately?	26.14%	23
No	63.64%	56
Total	100%	88

Yes, more than once - how many times approximately?

twice
Austin Water
3
3
2-3
annually
3
2
2
not sure
Probably every year for decades.
~5
at least twice that I know of
2
8-10 times
2
2

Permanently on an odd/even watering days
5
for the last 3 months
3
unknown

Q1.12 - Does your garden have a plan to manage the water needs of the living collection if long-term water restrictions are imposed? 'Long-term' means water restrictions lasting more than one month.

Answer	%	Count
Yes	25.84%	23
No	74.16%	66
Total	100%	89

Q1.13 - Please outline how your garden will manage its living collection in the event long-term water restrictions are imposed? 'Long term' means water restrictions lasting more than one month.

Our area is currently under water restrictions. We, luckily, have our own water source (well/aquifer) and just successfully completed digging a second well. Our first well is more than 100 years old and has never failed, but the water table was dropping to an alarming level. Even though we have our own water source we have self-imposed restrictions - we have let the "great lawn" die and many peripheral trees, hedges, etc. Many of our plants in the collections, such as palms, have been "trained" for drought by receiving deep and infrequent watering to encourage deep rooting. This coupled with soil building practices and woody mulches, many plants are buffered against drought, to an extent. We have switched to even more drip systems and creative, low-use watering methods. If our 4 year drought continues to a fifth year we will need to start prioritizing within the individual collections. We have many succulents, which although are suffering, are surviving. Our cycad collection will always receive the water it needs.

We will be restoring garden infrastructure and plantings within the next several years. New irrigation will include water catchment / filtration system designed to re-use runoff as irrigation water. The new system will be computer controlled, low flow.

One of the criterea for the collections is regionally adapted plants. If significant, repeated droughts occur, it is part of the selection process for the garden. If the same taxa dies repeatedly in responce to the same stress, it is eliminated form the collection.

Lawn reduction, first, conserving water for heritage trees and shubs. Reduce potted plants for color display

Let nature take its course. Impose a moratorium for new plantings and transplantings.

Irrigation removed during the summer months stage one, removed altogether in next stage.

We have constructed a backup reservoir and also have pumped water from our main lake into the irrigation lake to keep it operational.
Water bags for young and important trees increased monitoring of irrigation needs for more effective use of water
San Antonio Bot., and entire state of TX has had and will continue to have severe drought conditions. This is a perpetual problem here and one that causes great concern for the garden, city and entire state.
See the link on our website. http://www.filoli.org/drought/
We have a back up pond for the collection and we are also on municipal water system.
Topiaries and state champion trees will be given priority. larger trees and shrubs will be irrigated as needed. Most native trees and shrubs will be allowed to go dormant as long as they are established. Evaluation of seasonal bed areas and containers to decide which not to water. Most turf areas allowed to go dormant.
We manually irrigate select garden plants in order of priority: Trees (that aren't drought tolerant) Other woody plants i.e. shrubs and vines (that aren't drought tolerant) Misc plants that would be extremely difficult to replace T&E plants particularly if not waterwise We would accept the loss of herbaceous material, unless it rare or extremely difficult to replace.
Still in the planning process to expand the reclaimed water use on the property. This source of water is not restricted in a drought.
NA - our collection is stored in vitro
We are planting more native, drought tolerant plants. We are looking at drilling a well which is not restricted.
We can pump from a pond on-site.
We have removed all unnecessary lawn areas, we had water and use soil probes and meters to measure the need for water.
Water will first go to trees and shrubs to keep them alive. any water left will then go to turf and annual flowers.
We have our own water source and our long term plan is to limit irrigation to water from our own source, rather than using purchased water. To do this, we need to build more storage capacity, to maximize our water collection, increase stormwater infiltration, and improve efficiency of irrigation.

Q1.14 - Were there any challenges in developing and implementing this plan?

funding
No.
Yes, objection to lawn replacement and loss of functionality of lawn areas
Saying goodbye to some thirsty plants that would not make it through.
no
Added expense and staff time, I don't believe we have the in-house equipment and materials to utilize our new reservoir yet but will have to during any future drought like 2006 or 2012.
keeping our plan consistent with other (city and state developed) drought response plans
I'd say main concerns have been how to adopt/implement water conservation practices including funding of accessing and using recycled water, installing more and more water efficient systems and practices, funding all of these and working with city and various water utilities orgs. of special needs for the garden during times of various stages of water restrictions. City has never solved the water shortage problems to everyone's needs; extremely political issues to deal with and getting some exceptions to water useage is always difficult but so far city realizes the garden is a special case. I think our popularity with citizens and tourists has helped us a lot with special needs.
More so internally in having to decide how conserving we wanted to be. In the end, we struck a good balance so that our guests would not be impacted by the value of their admission and still doing our part.
No to date.
no
If the water shortage is the result of an earthquake, and subsequently major waterlines, we may not have access to water to implement the plan.
Cost and regulations governing reclaimed water use.
Native plants are not easily available in mass quantities in our location.
no
staff retraining, loss of lawn space
Athletic fields used for university sports were not included.
Fundraising for irrigation is difficult. No one wants to pay for pipes.

Q1.15 - Are there challenges and barriers that prevent such a plan being developed and implemented?

No

No

Being in east, it is not so much restrictions as access. If pumps or elec failed or some catastrophic event. We are working on incorporating plans to have water available, either stored on sight or tanker trucks.

Water restrictions are rare in our region so this issue is not top of mind.

Not sure how you can plan for such a thing, you have to respond to the situation at hand.

1. We do have sub-collection specific disaster plans (as Bonsai - an outdoor facility, and Conservatory). 2. We have consciously moved to reduce "general" irrigation and remove parts of the former irrigation infrastructure as un-sustainable. 3. We will be revising (significantly) our collection policy this year, so these are good issues to raise.

Time

human resources to develop the plan and manage the relationship between the city department and the non-profit partner. We have few people and many projects, plans and policies that are all good ideas that we 'should' do. but we can only accomplish so much.

No but it is a priority for the garden.

We use well water exclusively so are not restricted during droughts

right now too much water has been more of an issue - quick drenching thunderstorms as well as springs popping up.

time restrictions of the current staff

no

We are fortunate through our location in New England (Western Massachusetts) in having enough precipitation most summers and in having two deep wells, which have not run out during the last 25 years, for watering the gardens as needed.

yes--lack of volunteer resources. many more pressing issues need to be dealt with (and are not) for this reason.

We are a new botanic garden and have not had the staff time to develop these plans

staffing, knowledge of the issue, and time

No. In the case of the University of Georgia, extreme drought periods several years ago led to a complete ban of drip-line irrigation of on-campus gardens. The impact was minimal for this collection. Heavy use of mulch has allowed most plants to survive well and we have opted to only use spot watering when necessary, even after the "drought" period ended. The vast majority of species maintained in this garden are highly durable perennial species once established and we also maintain a large collection of arid species.

No, it just hasn't been a priority (or even discussed).

No.

None that I can see.

No, just the usual time restraints

No. My tenure goes back 30 plus years as a horticulturist in the Washington Park Arboretum and though we do not have a written water conservation policy based on collections care, we have substantially improved our water-use via more efficient irrigation systems (Rainbird MAXICOM) for newer exhibits and our new plant care team is more conscientious about wasteful watering. We rarely "blanket" cover all collections from summer rain regions and focus most of our watering on new plants (3 -year) program. We do have SOP's for irrigating manually - using the soil probe is our best method for determining if a plant needs water or not.

A plant collections management plan has been in early stages of development for several years, however limited resources and other financial priorities have thwarted progress.

No barriers. We have been switching to drip and low volume irrigation for some time. We have and are adding additional rain sensors to irrigation and electing to not install turf irrigation systems in parking and other low turf priority areas.

Developing a plan is not a priority since we have our own source of water.

No. However time spent to develop such a plan must be weighed against practicalities: a drip irrigation system is in place, and annual rainfall exceeds 55 inches.

No - we are on well water, so the local watering restrictions don't apply to us. But, our practice is to only irrigate to establishment, and we are not concerned about restrictions for the permanent established collection.

i believe our regular management planning will be sufficient.

too many acres, not enough staff, and the arboretum is not a primary function of this college. There are other priorities.

The will to make a plan. Short term thinking keeps us focused on the immediate needs. Strategic plan is only five years out, and makes no mention of water issues.

No. We are on a lake with the ability to pull from the lake or use city water. We prefer to draw from the lake due to the cost of city water for irrigation.

I am tasked with updating the entirety of our garden. It will take time before I can get to this plan because water issues are not our greatest threat.

We have onsite wells and available water nearby. The drought has larger impact daily and through heat in the air than on water restrictions.

Daily time constraints and ample rainfall over the past 2 growing seasons have lessened the urgency factor although we should address this in our Master Plan.
We have not had a full time curator on staff.
No.
Our relationship to central campus is somewhat poorly defined. We are currently in negotiations about how campus would provide water in the case of an catastrophic natural disaster (in our case, earthquakes/slides, and wild fire.
While the City of Northampton may have water restrictions, it appears Smith is still exempt. Amherst (north of us) on the other hand cannot water their lawns (turf) when there are water restrictions per Brandon Adams employee at Grounds at University of Mass. Amherst.
Not having a staff person to dedicate time for such a project. Really do not have a registrar to record data on a regular basis. Our garden has primarily been a display garden and in recent years more of a rental facility for weddings, etc. We also focus on entertainment, such as a summer concert series, wine tastings, etc.
We have wells on the property that we would like to use, but dissolved iron and manganese in the water stain structures and plants when it is used. Inexpensive treatment is needed to address this problem. Until then, we are using water from the municipal water works.
the cost of drilling wells - very expensive, and you might not even hit water; time with limited staff to develop a plan that may or may not ever be useful
Time, personnel - all the usual
We have a long term lease on County land and share water lines with the surrounding County Park. Our water use is not managed separately from that County Park, although we use water conservation methods at our botanical garden.
Developed, no. Implemented, none other than trying to prevent plants from dying should restrictions be severe.
Just the time to do so.
The time to get it completed. Because the threat of drought or water restrictions is not big in our part of the country, there is not much motivation to complete it when the "to-do list" is so long.
Staff number and time availability

Q1.16 - Does your garden have a plan for the short-term survival of its living collection in the event the water supply is suddenly shut down? For example if the water supply infrastructure breaks down?

Answer	%	Count
Yes	32.56%	28
No	67.44%	58
Total	100%	86

Q1.17 - Please outline what your garden will do to protect its living collection in the short-term if the water supply is suddenly shut down?

It will depend on the breadth of the shut down. If it is local to our facility we can truck water in. if it is a city-wide shut down, we have limited options.
We have a mobile water tanks and a supply of mobile irrigation devices.
We will hand water irreplaceable plants from our bodies of water.
We presently have a 1,000 gal. water cistern and are constructing two more, which capture water-runoff from building roofs and store it. The irrigation system is being designed to tap into those sources should the irrigation wells malfunction.
We have a redundant irrigation system and city water backup and also cisterns in some cases.
We do have a 10,000 gallon cistern that collects water from the roof of our greenhouse complex. This water would allow us to maintin the plants inside the greenhouse and in nearby nursery/growing areas for a period of time.
Rain water harvesting system and irrigation from ponds.
We have redundant systems with back up wells if needed, which have an established order of use depending on water quality (salinity).
utilize cisterns and lake water
We irrigate 90% of our 80 acre garden with collected rain water. We also transfer water from streams bordering our property.
We rely on gravity system, some of which is 100+ years old to supply much of our outside irrigation. We have back up tanks and potable systems to use in emergency situations. For the conservatory, we use potable water system and can back up with old system.

We have a pump system set up in a pond to irrigate with. We also have water trucks available as well.
We may pull water from a nearby stream, however this will need to be needs of other creekside owners
We had a mainline break this year and had to tap into distant water sources using hundreds of feet of hose and sprinklers. If all water were out for the campus, we would have a lot more to worry about than just the plants.
hand watering
We have the ability to switch back and forth from lake water or city water.
We have 4 separate well systems set at varied water tables and areas of the property. they are on different power systems. We also have availability to have a tank delivered if vital but have never come close to this need.
Connect from fire hydrant to irrigation mainline in well house. Was done in 2006 when well collapsed.
If water is suddenly shut down we have a prioritized list of water-sensitve and irreplaceable (often endangered or threatened) plants we will focus on in the short term.
Buckets! Some rainwater collection, though in drought conditions that would not be effective.
We have a pump truck with a large tank that can be used to do some watering.
We would bring water in using partner organization water trucks, or utilize water lines connected to the County Park.
Use a water truck with water brought in.
We could use our own water source to water plants, and if that failed potentially pump water from our artificial lake to keep plants that are irreplaceable. Plants would be prioritized according to our ability to replace them.
If for some reason the rural water supply is shut down, we will be pulling water out of our two ponds to water plants/trees.

Q1.18 - Do you have any other comments to make about the preparedness of your garden for water shortages or water restrictions?

Being in southern California, cyclical drought is a reality so we realize that rainfall is something we can never depend on. Even in years of average or above average rainfall, it can fall in the span of two months leading to 6-10 months of seasonal drought until the next rains. Water conservation is always at the forefront of our planning.

This is something we need to work on. We should look for a good graduate student to develop a plan for us

This is an issue that is on the forefront for us, not due to drought but in case of catastrophic events here in the Washington area. On top of important medicinal, native, orchid and economic collections we have historic collections as well as collections of rare plant material that would be important to save.

We are on wells and have never experienced any kind of shortage.

We have up to 48 hours of water (summer demand) for the Conservatory on hand. We have our own backup electrical generator to run the pumps and emergency works (its about the size of a small railroad wagon - an industrial size). For us, a heat (cold) emergency is more likely, but that is completely different issue, and what our emergency collection planning is focused on.

We only water specimen trees for the first 3 years after installation (in general). we don't have the resources to do otherwise. We give preference in all of our plantings to plants that are hardy, can take a bit of neglect if necessary. if we went through drought restrictions like in the past we would limit the many of the display beds that contain more high maintenance including some annual beds.

The main water source for the gardens is municipal/potable water. Being part of a large university adds a high level of security ensuring a safe constant flow of water, however, I acknowledge this is not a guarantee from potential water delivery failures.

So far our wells have never gone dry so we have done well during droughts

We have wells as well as municipal water supply, and we are surrounded by a reservoir.

soils are mulched to retain moisture, soils are amended and enriched to assure healthy aggressive roots.

We are most fortunate to have a plentiful supply of water at our garden - our region has not experienced any significant drought and gets a heavy snow accumulation each year as well. The site has a number of artesian wells, perched wetlands, and a creek as well.

we can--and do--live with the annual water restrictions which are entirely based on days of the week. Were the water supply shut down we would need to return to bringing water into the garden manually such as we did prior to installation of the public water supply a few years ago.

no
We have built 3 large retention ponds and a 400,000 gallon cistern to better prepare for water shortages in the future
We would have to hand water highest priority plants from water remaining in lakes and ponds and probably need to address this in the accessions policy.
Many of our collections are from South Florida, the Caribbean, and other dry tropical areas such as Madagascar and are adapted to seasonal drying. The remaining plants that may require more water would either die and be replaced with drought tolerant species or be the focus of a specialized watering regimen. We have grouped many of our thirstier plants into 2-3 zones so we can focus watering efforts on those areas in order to conserve resources, in general.
This survey has made us aware that having some system in place, or at a minimum reviewing resources at the university, should such a complete shut-down of water take place, would be useful. For example, we have the space and resources to very easily build a rain barrel system.
Except for our greenhouse, we don't rely heavily on supplemental irrigation for plants in the landscape/gardens. We do have about 40 large ornamental container plantings around the gardens, which we water every other day on during dry weather. Other than that, only new plantings need to be irrigated. We don't water our lawn areas, for example. So we don't feel that the typical types of water restrictions due to drought (no overhead sprinklers, no refilling of fountains, etc.) would affect our operations very much.
No.
The restricitions we have had to implement involve timing of water use during the day. We have not had to use a smaller volume of water. It has really only impacted turf management.
This is a big strategic issue -- right at the heart of what we all do. Thanks for taking it on. Our longer term plans include a strategy for dealing with saltwater intrusion.
no
Seattle City Parks and Rec pay for all irrigation water that is used to irrigate collections (UWBG) and turf (City). If water restrictions are imposed, we (UWBG) would do our best to comply. Our collections development is flexible enough to postpone new installations. We are also focusing future development primarily on winter rain region plants (similar to our climate) that theoretically would not need summer water once established. Our collections at our other site, Center for Urban Horticulture, are irrigated and billed under UW campus infrastructure budgets, so we do not pay for the water at CUH either. However, we do our share to conserve and would comply with campus if restrictions are imposed.
We do have access and do use recycled water at present. If entire city water system shut down we'd have to be considering bringing in water for use on most critical

plantings and would probably stop planting seasonal displays all together. Our non-native areas and conservatives would suffer terribly if zero city water available to us.

Our public garden has need of a botanical collections management plan-time and resources have not been prioritized to the development of such and we acknowledge the lack of such a comprehensive plan of action to encompass the preservation and conservation of our plants.

We are fortunate to have our own sources of water on the property and take pride in the fact that the water leaving the property is as clean or cleaner than when it enters. The majority of our plants or plant types have been growing here for 50 years or more and are suitable for our climate.

It is critical, particularly in the west where earthquakes and drought exist.

we have cisterns that collect water, we have wells, we have a creek and pond, and we have city water. public gardens in the past have been given permission to hand water.

no Another threat our Collections face is from the potential of fire. We have installed wildland standpipes along the border of the developed gardens and our Natural Areas. In the event of a fire, the fire dept can connect the system to a water source and use it to protect the developed portions of the Garden.

We have changed irrigation heads to low volume spray heads. That and swales to keep water on the property allow us to make the best use of this valuable resource.

We are fortunate to have always planted drought adapted native plants. And we have made excellent progress in recycling our waste water for use in the gardens. We use only drip irrigation.

This is an issue that should be addressed by every garden before it becomes a major problem.

We have a couple of new rain barrels and are talking about a cistern for rainwater collection in the future master plan.

Future planning for new areas includes detailed research into care requirements, water needs, plant adaptability, and   companion planing. Current garden zones are intensive maintenance and require careful use of companion planting, watering, and maintenance.

We are fortunate to have an abundance of springs on our property and a few small spring fed ponds available to supply water.

No

Due to presence of Great Lakes nearby, water restriction might be unlikely, but we have transitioned some annual planting beds to perennials, are using more native plants, and have created xeriscape garden areas.

As mentioned above, while we have a plan we have less than clear campus buy-in in terms of spelling out how water would be delivered in the long run.

no

Good water management in times of abundance helps to ensure plants are strong enough to survive at least short periods of drought. No overwatering, if possible. Also, maximizing irrigation efficiency under routine circumstances helps to prepare for sudden shortfalls.

At the present time, the Memphis area has not had a serious water shortage. We do have some of the best quality water in the country from an artesian well. I know it is not realistic to think this will continue for ever. Our garden is managed by the Memphis Botanic Garden Foundation, but the facilities are owned by the City of Memphis. There is very little interest by the city in the conservation of water. Emphasis is on crime, housing, schools etc.

We have drastically reduced water use with automation of our irrigation systems.

We use a well to water most of our collections, city water for some areas the well can't supply. The well is our plan in drought conditions. If it dries up though, we'd lose a lot of plants I'm sure. Fortunately our collections consist primarily of established native forest and native plant gardens, well adapted to drought periods. We have so few 'rare' plants and significant trees it wouldn't be hard to just keep those going on the well. I answered 'no' to the water restriction question, but can only go so far as 8 years, I'm not sure before that if there were any restrictions before that time.

Thanks for giving us something else to worry about! This is not a topic we've given much thought, but it is something we should be addressing.

Frequency of watering is currently our primary means of following "better" water management. For example, my predecessor watered the bulk of our woodland collection daily for 2-3 months. I water it every 2-3 days.

Part of the reason we do not have a plan for loss of water supply in the short term is that we have no irrigated areas and have deliberately collected plants that do not require supplemental watering except during prolonged dry spells.

We are in the midst of a new water conservation project that should put us in a much better position, but we must get through that before we can plan beyond it. This is a challenging subject, and we are lucky in that we tend to get a decent amount of rain on our site right now.

I feel as though this is something we need to consider more carefully moving forward.

Try to irrigate efficiently and well to develop healthy roots and plants to survive some stress.

Our gardens have been ahead of the game on water since they begin- the original owner bought the water company and piped water to the gardens, which we continue to have the right to. We started making changes in 2011 to further improve our use. We are making well over our required 35% reductions of purchased water this year, mostly by changes we made to the system on the advice of a group of water experts we brought together 2 years ago to advise us on improving our resource use. Their advice was instrumental on choosing which steps to prioritize to reduce the majority of our use. Tracking water use was an important first step in that process.

Q2.1 - Where is your garden's water primarily sourced from?

Answer	%	Count
Municipal water supply	54.65%	47
River or stream	1.16%	1
Ground water	30.23%	26
Surface water harvested and stored in a reservoir	5.81%	5
Desalination	1.16%	1
Other	6.98%	6
Total	100%	86

Other

Other
We have 2 sites: one on municipal; one now on municipal but with wells, too
lake
reclaimed sewage water
municipal and surface
ponds

Q2.2 - How much water does your garden use each day to irrigate its outdoor living collection?

Answer	%	Count
Quantity:	16.67%	14
Don't know	83.33%	70
Total	100%	84

Quantity:
avg. 700,000 cuft / yr
Minimal
majority of water used outdoors
2in/ week over 10 acres, adjusted for rainfall
5,000 gallons
spot watering only a few times each week.
varies
Varies by season. Yearly average of 10K gallons per day.
4716381
0
Varies by day - 2014 seasonal use was 623,531 gallons
0
44,000 gallons

Q2.3 - How much water does your garden use each day to irrigate its greenhouse living collection?

Answer	%	Count
Quantity:	23.17%	19
Don't know	76.83%	63
Total	100%	82

Quantity:

avg: 160,000 cuft / yr
No greenhouse collections
445 gal
minor amount
n/a
none-no greenhouse
0
less than 500 gallons
175,750 gallons
none
10 minutes with 1 hose
250506
400
0
No greenhouse living collection
0
0
330 gallons

Q2.4 - Describe the type of irrigation mainly used in your garden? For example, is it an automated system, portable hoses, drip irrigation, sprinklers, hand-watering, or some combination?

All of the above
All of the above, though use varies with need and specific conditions of the particular growing season.
portable hoses, hand watering, new sprinkler systems are going in, we just completed a new irrigation mainline system that is designed for use with recycled water
A combination of all of these
We have a combination of hand watering, portable house, automated systems, drip irrigation and sprinklers. NOTE: above question- we can't have separate meters for outdoor and indoor. the totals I gave for outdoor is everything that is in conservatory and outdoor gardens that are open to public. The 'greenhouse' number is our production and back up greenhouses and growing facility. These also include sanitary and drinking water numbers.
Combination of all types
Annual displays are irrigated with sprinklers when needed. Nursery plants are hand watered.
automated systems, hand watering, high volume, long throw system (ie: vegetable field type irrigation)
A combination of all of the above.
We are mainly on a centrally controlled Motorola system
Conservatory: Mist-system (for humidity) is automatic. Irrigation is all by hand. Conservatory is ca 20m wide x 65m long Outdoors: where there is irrigation it is all via quick-couplers for hand-irrigation or manually operated sprinker systems
Combination: automated systems, portable hoses off of fire hydrants, hoses off of building, drip irrigation, sprinklers, etc.
Trees are usually watered by a water truck. We use a combination of handwatering with hoses, some sprinklers and some drip hoses.
all of the above
Hand watering, gator bags and similar, minimal in ground coverage.
No green houses. we use overhead sprinklers and hand watering with hoses
portable hoses, sprinklers, hand watering & drip
if we irrigate at all it is portable hoses and on very rare occasions sprinklers

We have automated, hoses, sprinklers, hand watering all in combination
automated irrigation zones with pop up rotory type heads
Automated sprinklers primarily. Hand watering new plants. Drip in the grid-planted research areas.
We are presently transitioning into an automated system with a strong emphasis on water conservation (i.e. drip irrigation vs spray, rain sensors to eliminate unnecessary irrigation, hook-ups to water-storing cisterns, etc.
We irrigate our living collection through a combination of all of the ones mentioned above.
portable hoses, hand-watering
Automated system, R/O system, hose bib
automated and manual systems
Automated drip irrigation and some sprinklers.
We have a combination but mainly hand watering with portable hoses and sprinklers. We have some drip and plan to convert more areas to drip.
We have a microflow sprinkler system for most of the garden. Potted plants are watered by hand and an underground cistern captures grey water from our resort's laundry system which is reused in our tropical fruit garden and front lawn.
Hand watering in the garden and combination of hand watering and misting benches for germination.
a combination of all of the above depending on location in the system
Mostly hand-watering with hoses. Some portable sprinklers on larger new plantings.
automated irrigation system
Drip irrigation, sprinklers and some hand-watering.
A combination of all of the above. Greenhouses are only hand watered.
a very complex combination.
all of the above
Mainly automatic. Portable hoses and sprinklers second, handwatering is third, drip comes in fourth - greenroofs and farm (tape).
Lots of drip, irrigation systems in turf and many outdoor gardens, still a lot of hand watering outside and in greenhouses. Use recycled water in many areas of native plantings.
Combination. Mostly sprinklers, some drip, some hand-watering of containers. The greenhouse and conservatory are almost all hand watering with some mist in our

propagation house.
Hand-watering.
Hand watering
combination of all the above.
combination of sprinklers, portable hoses and hand-watering
Automated drip and micro-irrigation system for most of the garden. Portable hoses and overhead sprinklers as needed for areas not within the drip irrigated system.
all of the above
Combination of automated system, sprinklers, and hand watering
Automated system of turf and beds. Pots are hand watered. Some portable sprinkler use for dry spots.
Aut0matic irrigation system - Rain Bird Site Pro. We can control all of our irrigation from a central location and the ability to use ET rates.
portable hoses
30% automated. 50% portable hoses and sprinklers. 20% hand-watering
combination of automated, sprinkers and hand watering
sprinklers, managed by SiteControl irrigation software It also connects with a Weather station to get data on ET, rain, temp, etc.
Mostly automated with some drip irrigation in border areas that have been colonized by the Medicinal Herb Garden.
automated
In-ground irrigation for two athletic fields and two collge greens. Water truck for gator-bagged trees in hot weather. Hoses and sprinklers in hot weather for small bedding areas.
Automated system combined with hand-watering select areas
automated from a central controller with flow meters throughout for reporting on water use and issues. primarily drip irrigation with some hand watering.
mainly irrigation, and handwatering of pots or out of the way spots and our nursery
Right now most watering is by hand. We occasionally use sprinklers or irrigation. Irrigation in some parts of the garden is not functional and in need of repair. We plan to install an automated system in the greenhouses as that is our most time-consuming to water by hand.
combination of sprinklers, hoses avoiding foliage, and drip lines all monitored closely and hand directed during the hand watering process.

Combination of frost free hydrants and sprinklers and hand watering.
NA
Mainly hand watering with portable hoses and some overhead impact sprinklers. Turf irrigation automatic with sprays, rotors, and rotary emitters. One shade garden has an automatic irrigation system of sprays, rotors, and rotary emitters .
Our irrigation system is being replaced by campus as part of a 5 or so year plan. The new system will be fully automated. We have already changed out irrigation heads to more efficient models garden-wide. We use a combination of automated, hand watering (actually turning on irrigation risers in most areas of the garden), portable sprinklers, etc.
nothing automated inside (except mist bench); outdoor sprinkler system goes on at night mostly.
Mostly hand watering with hoses, partly drip irrigation on timers. One area on timed mist.
Primarily, in ground irrigation system to cover outdoor areas. (approximately 85 acres) Greenhouses are a combination of hand watering and irrigation.
automated system and hand-watering with hoses.
automated system and some sprinklers.
mostly automated irrigation with rotors and microsprays, some sprinklers we rotate around the dry areas, and hand-watering for pots
A little is automated, some portable hoses. New plants are hand watered but after established most are allowed to be water stressed in order to evaluate them.
All of the above
Combination of automated and manual drip irrigation and sprinkler irrigation supplemented by hand watering.
combination of autmated systems and hand watering. Mostly hand watering as we are a small 2.2 acre garden
Automated, portable sprinklers and hand watering.
On a daily basis we do not water anything. But, during dry spells we do use portable hoses and hand-watering for newly planted parts of the collection.
Ancient high-pressure quick coupler system. It is very old and wasteful. Mostly it is manually controlled.
A combination of automated systems and hand-watering outdoors. Most of the automated system has pop-up overhead sprinklers. Indoors is exclusively hand-watering.
Automated system
automated systems and portable hoses supplemented with hand watering

We have an automated system for the most part, mainly drip with some rotors and pop ups for turf areas. Have a central control system for approx 1/5th of site with a master plan to complete. for question above we do not have a green house. Also we are not able to meter most of our system as it is metered along with buildings. Will change with Master Plan and central control system.

We have every type of irrigation imaginable from 1940s pipes and 1960s rotors, to weather based clocks.

Sprinklers

portable hoses and water tank on a wagon

Q3.6 - What is the total annual budget of your garden?

about $50 million US
$11mm
4.2 million
~2 million
$550,000 garden, $8.5 million institutionally
$2.5 million
2.3 million dollars
$14.4 million
$500,000
3.6 million
$180,000
$70,000
n/a
$1,000,000
~$40,000
10 million
$1.2 M
$3,000,000
$100,000
Between $5K - $7.5K
$3 million
50,000
$850,000
$1,200,000.00 (approximately)
1680000

approx. $40 million annually
1 million operating funds
Not sure. I can find out from Director is really needed. We are considered a "Large" garden via APGA guidelines so it must be several million for ops.
$6M
2 million
$1 million
$5000
7M
$300,000.00
$4.5 million
$500,000.00
My salary as a gardener, about $42,000.
2M
6,700,000
493,126
it's complicated- officially our budget is less than $3000 but the college picks up the tab for much more, probably $25,000 not including salaries; salaries are about $100,000 per year plus benefits
750000
Has not been tracked in the past.
1.9 million dollars
$2M
200K
$3,500,500.
3.8 million
$11,000,000; however of this about $5,000,000 is the budget for the gardens and collections on the Washington campus

343,860
850,000
$360,300
1.5 million
$220,000
$3,000 (for the garden itself; we are a university so our facilities staff is paid out of a facilities budget)
$18 million (thereabouts)
approx 2.5 million dollars
2,000,000
99,000
The entire campus is an arboretum so budget is for all landscape maintenance
~$1 million
230,000

Q3.7 - How many full-time equivalent positions (FTE) positions are there at your garden?

250 aproximately
66
45
35-40
9
500
45
ca 20
59
6
27
3
one
8
12
1.5
10
0.1 paid, several volunteer
120
12
53
1.5
None. There is One 1/2-time curator.
7
5

1
5
8 full-time year-round (15 seasonal 40 hr/week and part-time positions totalling approximately 15,600 hrs annually)
25
400+
30 FTE
Will have to ask Director if needed.
65
17
60
18
0
4 to manage the garden
14 garden; 40 organization.
2.75
26
4
16
40 something
Just me
50
5 on arboretum side, 9 on grounds and athletic fields side
28
125
8

3
3.5
12
2
22
32
13
40
48
30 involved in gardens and education, a total of 65 including research and administration
7.5
9
3
4.8
24
3
0.5 for the garden itself (this excludes the many groundskeepers the university has, who mostly mow)
160
30
9
1.5
There are 70 FTE on the Grounds crew
11
2.25

AUSTRALIA SURVEY

Q1.1 - What is the approximate number of living accessions recorded in your plant database as growing in your garden? (i.e. not the total number of individual plants but the total number of accessions)

8000
16000
4200
4000
4,000
7,800
1000
48,840
400
Garden in planning stage.
not recorded
These will be forthcoming
7991
2000
2500
unknown
2000
We have no plants recorded on the data base at this time, we have just set it up to start recording this year.
300
1800
16000
1200

5000
4000
220

Q1.2 - Does your garden's living collection include any of the following? Check all which apply

Answer	%	Count
Plants cultivated from the first plant collected to describe the species (i.e. the type specimen)	25.00%	9
Documented wild collected plants?	61.11%	22
Documented wild-collected IUCN Red-List plants?	47.22%	17
Rare cultivars?	50.00%	18
Plants that are difficult to replace due to restrictions on collecting new material?	69.44%	25
Plants that are expensive to replace?	72.22%	26
Heritage trees?	58.33%	21

Q1.3 - Are the important plants in your garden noted, either on a separate list, or flagged in the garden's plant record system? 'Important'' plants might include, for example, wild collected species, rare cultivars, heritage trees, plants cultivated from the first plant collected to describe that species (the 'type specimen') or plants that are otherwise significant to your garden.

Answer	%	Count
Yes	77.78%	28
No	22.22%	8
Total	100%	36

Q1.4 - Does your garden have a plan for managing or responding to natural disasters which may impact its living collections? As an example, a disaster management plan for the living collection might include management of cyclone and storm damage, floods, earthquakes, pest and disease outbreak, drought or extreme cold or heat.

Answer	%	Count
Yes	34.29%	12
No	65.71%	23
Total	100%	35

Q1.5 - Does the disaster management plan for the living collection include a strategy to manage water shortages?

Answer	%	Count
Yes	58.33%	7
No	41.67%	5
Total	100%	12

Q1.6 - Has your garden lost any important living collections due to drought or water restrictions in the past 20 years?

Answer	%	Count
Yes	27.27%	9
No	72.73%	24
Total	100%	33

Q1.7 - Please describe what collections were lost?

Primarily remnant trees in bushland and some memorial avenue trees, which are growing in areas that have never been irrigated.
A small range of accessions, largely due to the extreme weather conditions and despite a focus to limit the impact by adopting a range of strategic and triage stategies throughout the drought period.
Sp. from the Australian tropical and sub-tropical rainforest collection. Tree ferns from the fern collection
tree ferns; species from native tropical and sub tropcal rainforest collections;
A single specimen of Araucaria araucana was lost during 2013 drought
A very significant Callistris in terms of size and shape
The Maroochydore Botanic Garden is 100% Australian native plants local to the Sunshine Coast Bio-Region. Large Eucalyptus trees.
Acacia karoo, Callistemon brchyandrus - both heritage trees of state significance in Victoria, Australia, as well as many pinus trees estimated to be between 140 and 150 years old (garden established 1857). The drought in the 1990's, the neglect from the 1950's-1980's all contributed to the loss of trees, as the irrigation system was only installed 2007.
Mature trees and relatively new plantings

Q1.8 - Does your garden have a living collections management policy or purpose statement that describes what your garden collects and why?

Answer	%	Count
Yes	61.76%	21
No	38.24%	13
Total	100%	34

Q1.9 - Has your garden changed its living collections management policy / purpose statement in response to current or potential water shortages?

Answer	%	Count
Yes	40.00%	10
No	60.00%	15
Total	100%	25

Q1.10 - Please describe how your living collections management policy / purpose statement has changed in response to current or potential water shortages.

A greater emphasis on cultivation of plants that are suited to the climatic conditions of the gardens - this transition will occur over time.

The Living Collections policy and operational plan now features conserving and using water effeciently as a priority and outlines various stategies to identify opportunities for water saving and matching plants requirements to water requirements.

Focus on drought tolerant species for new areas of garden.

In regards to the future development of living collections we have made it policy to consider collections that will be suited to a drier climate with less rainfall and requiring less frequent irrigating. Essentially, collections that are more suited to our climate.

Through plant selection, Integrated water management, creation of a Strategic Water Plan, development of a Landscape Succession Strategy that takes into account climate projections of 2090

The incorporation of sourcing species that are climate compatible within all collections policies

Our Collections are geographic. We are moving away from new plants from high precipitation areas to those from lower. Of course we cannot ignore we are currently in a 1m isohyet with a lower summer precipitation which limits how dry and our temperature regime is also a limitation.

Our new garden expansion (the Garden for the Future) is focusing on dry climate plants and plants suited to a changing climate. The heritage garden is replacing heritage trees with similar but more drought tolerant species especially in the area of conifer selection and deciduous trees.

We have categorised our collections in terms of importance with a specific reference to irriation priorities. Most of Wollongong Botanic Garden is irrigated with potable water, and whilst not currently under water restrictions, we do have a current issue with over-expenditure of water budget allocations. Regardless, the collections plan is now listed in the event of extreme drought or budgets cuts we have identified collections that can effectively be 'sacrificed' with no further irrigation, to ensure important collections continue to receive water.

All future plant selections for displays and understorey in garden beds will be low water requirement.

Q1.11 - Has your garden had water restrictions lasting for more than one month in the past 20 years?

Answer	%	Count
Yes - one time	14.71%	5
Yes, more than once - how many times approximately?	41.18%	14
No	44.12%	15
Total	100%	34

Yes, more than once - how many times approximately?
winter restrictions apply annually; watering occurs in accordance with an agreed groundwater licence operating strategy to which some bans do not apply.
2
7 year period
5
3 years
5
six
10
7
no garden watering allowed until 2007
throughout 2000-2010
3 times

Q1.12 - Does your garden have a plan to manage the water needs of the living collection if long-term water restrictions are imposed? 'Long-term' means water restrictions lasting more than one month.

Answer	%	Count
Yes	60.61%	20
No	39.39%	13
Total	100%	33

Q1.13 - Please outline how your garden will manage its living collection in the event long-term water restrictions are imposed? 'Long term' means water restrictions lasting more than one month.

Current garden bed water management is at a minimum application rate allowing the plants to adapt to restrictions. Turf areas are ranked according to priority for water use. Turf areas have been identified as potential areas for further reductions or shut down if water availability is further reduced.
The draft Living Collections policy and operational plan now features water conserving and using water effeciently as a priority. And since the impact of the drought the ANBG has applied a pro active approach to innovative and strategic focus on water management. We have a strategy that adopts the principles of triage actions as the level of restriction, threat escalates this includes enacting regular meetings and engaging with stakeholders to determine and implement the best strategy for the circumstances. Priorities include provision for sourcing, priorities for watrer application relatingto the capacity of the collections to tollerate lower soil moisture levels and method of water application / mitigation and harvesting.
* Stormwater harvest dam has been built to reduce the ongoing reliance on potable water * New irrigation system being installed which is more efficient in delivery and can use either potable or recycled water. System able to deliver water by water use zones. * Some collections considered to be more drought tolerant will recieve minimal irrigation, others enough water to maintain plant health
Onsite water sources & recycled water
plans have been implemented to irrigate the collections from overflow lakes that have been constructed as part of a redevelopment.
We are in the process of installing a system to recycle grey water (sewerage) back into the water thirsty turf. This will reduce the draw on our only dam. Our Strategic Planning Framework highlights the need for an additional dam to be installed to cover the site's needs into the future.

Please note that our 'living collection' is located in a desert and only consists of species from this desert therefore most plants, but not all, are highly drought resistant. We are also blessed with a large artesion basin supplying us with water so we have never suffered water restrictions. The cost of water is another matter with this going up a factor of ten times of the last few years. To meet budget demands we have turned water off to sections of our garden that are not part of the public area and that consist of highly drought resistant species
1. Established / significant trees to be priority no.1 in relation to irrigation allocation. 2. The remaining living collections take next priority. 3. Allow lawn areas to 'brown off', if necessary. The lawn areas would become the lowest priority.
Gardens are heavily mulched,dry tolerant plants are selected
A stormwater harvesting project - Working Wetlands was implemented to harvest water from surrounding streets and store in our lakes system, it can then be pumped into our irrigation system, offsetting potable water use by 40%. Planning is underway to use 100% sustaianble water for irrigation and become non-reliant on potable water. We also have an excellent relationship with our water wholesaler and retailer that assists when exemptiions to restrictions are possible.
Mount Lofty Botanic Garden has an independent water supply . This is rain catchment and supplemented from several bores. While we have an annual allocation this should be sufficient into the future. This was a plan developed from the inception of the garden in the 1950s.
The construction of the first Creek Wetland and aquifer storage project is aimed at future proofing the gardens water requirements. The gardens will review irrigation practices across lawn and non essential amenity displays.
Expansion of recycled water system as budget allows.
Using local native plants reduces water usage significantly. We have a large water reservoir on site as well as a reliable bore.
Water trucks, change plant palette to plants which don't need irrigation
We can change from potable water to stored water
Internal water rationing program developed with key areas maintained and lower graded areas gradually reduced or stop water.
As per previos statement - we have identified 'sacrificial collections' to ensure water is used on our most important collections. sacrificial collections are display beds, and collections that can be readily replaced.
Bore system installed and maintained. Legally cross connected to town water ring water-main system, with separate potable drinking water system. Storm water harvesting possibilities explored and approval process in place if needed. Tree collection is first priority, important shrub collections second, turf areas to be maintained in drought, allocated as 15% of total turf area.

Q1.14 - Were there any challenges in developing and implementing this plan?

The most critical challenge is the relationship between the trees living in turf areas and working out how best to manage the trees to adapt to less water. We have adopted a transitional reduction in many turf areas to try to drought proof the trees should additional water restrictions be imposed.

Not really, we collectively pooled our expertise and sought advice from external specialists and regional institutions to collaborate on the best outcomes.

* cost of infrastructure * retraining of staff to use new irrigation system and now focusing on developing a greater understanding of plant water requirements

yes- financal implications

yes, financial

only financial

No as the it was simply a matter of selecting areas to turn water off too. These were self evident.

The general consensus amongst staff was that this was the right thing to do. The most difficult issue to deal with is getting the public on board as they love our lawn areas and many of them object to these areas being allowed to brown off. It takes quite a bit of careful PR work to keep everyone informed.

Not really

Plenty, funding, construction, operation. Having dedicated staff in this area is a must.

Funding for replacement refurbishment of pumps and delivery lines etc.

Budget.

No

Plant selection is critically important, the hardest part is convincing others who don't understand the limitations on plant selection. It's political to say to some in local government circles that we won't be replanting high, water use, heritage plants such as Elms, Pines, Willows and Poplars and will be replacing them with Oaks, Dry climate Pines and other trees that may not have been planted on the site before. Many in the nearest main city of Melbourne, still don't understand how hot and dry it is in <TOWN> compared with Melbourne. (2 hour drive away, but half the rainfall, and more extreme temperatures in <TOWN>)

Some infrastructure upgrades

Never implemented, fairly confident that senior management do not recognise the impacts if ever implemented.

No - it has not yet been required to implement the plan, this will certainly cause disruption to service. For example: Wollongong has a number of display beds in high use parts of the garden that will be the first collections removed under extreme water shortages.

Comprehensive consultation process and bore water table levels are diminishing progressively.

Q1.15 - Are there challenges and barriers that prevent such a plan being developed and implemented?

No. We mantain a collection sourced entirely from the arid zone in which the Bot G is located. Natural disasters are part of the living landscape here. Should they impact our garden the problem will be one of infrastructure rather than loss of plants as almost everything we have will grow back. Some rare plants are located in fire safe zones simply because many rare plants are those that live in moist environments and cannot be located in fire risk areas. due to the nature of our collection restrictions will not greatly impact us. We use minimal water as it is. Our water supply is also ground water and the reserve is very large ie estimated to last over 300 years by CSIRO scientists and then there are other reserves. We are still very water conservative and water conscious as 300 yrs is not for ever and we are concervationists in all ways.

There is not the interest or support from the higher powers in the organisation. Being Local Government there are many services they provide and the Botanic Gardens is only one. There is currently not the resources

budget, importance of

We use bore water to irrigate and the bore has not run dry in 30+ years. The one area of concern we have is the sale of water Commercially, to companies like Coca Cola for use in Mineral water. There is a fear that the amount of water being taken off the Mountain will effect the level of the aquifer. It appears that this has happened in other areas of the Mountain but so far we do not have any commercial bores that are adjacent to our Gardens.

Yes reliable rainfall. Abundant water supplies

National Parks Plan of Management may pose issues?

WE have now installed reclaimed water irrigation to the gardens this allow us in time of water restrictions the ability to hand water the few plants that are sensitive to the reclaimed water. The reclaimed water is a guaranteed supply.

Time, staff and necessity. Currently our plants have to survive or fail through summer after 3 years although we may be about to review that given the rainfall outlook and climate modelling.

No - our species are all plants native to our region and well adapted to hot, dry conditions; we typically only water them during the first two years

Q1.16 - Does your garden have a plan for the short-term survival of its living collection in the event the water supply is suddenly shut down? For example if the water supply infrastructure breaks down?

Answer	%	Count
Yes	60.61%	20
No	39.39%	13
Total	100%	33

Q1.17 - Please outline what your garden will do to protect its living collection in the short-term if the water supply is suddenly shut down?

We have an alternative water supply and back up pump station in the event of failure of the main groundwater supply. The nursery has both scheme/mains water and a ground water supply, also with the back up pump station and alternative water supply source.
It depends on the scenario length of time, weather and alternative supply options, all of which are discussed if this scenario eventuates.
Use of the stormwater harvest dam which is connected to the irrigation system. Transport of recycled water to site tanks which can then run through the irrigation system.
on-site water supply & ablility to use pottable water if our irrigations pumps fail
we will get the problem fixed, but we can switch over to the mains water temporarily and run the system manually.
Most of the collection will survive for a number of weeks without water so there is little or no risk there. Water sensitive species and for our propagation facilities we would transport water in and hand water.
Once again dry tolerant plants are selected
Use our stored lake water and we have a full time plumber, qualified irrigation staff and technicians available at short notice to deal with any infrastructure issues.
We have an underground water tank that stores stormwater runoff. It holds152,000 litres. we could also use our water tank to cart water in from other areas and hand water. We have a regular mulching program and using wetting agent every time we plant. This helps reduce water loss and increases the soil's water holding capacity.
There are several backups including a diesel pump and a Diesel powered generator to replace electricity . These are the issues that will have an impact on supply. There are

also battery operated Automated systems on the most valuable parts of the collection that may be impacted by extended periods of garden closure due to high fire danger ie when no staff are present either.
There back up supply sources, such as recycled water and multiple meters that can supply water across the garden. The Wetland aquifer storage system. The lakes can be used to pump water to key collections
Bores and lakes in the garden can be linked to the irrigation system
We don't use water from off site. Use adaptable native plants that will tolerate these conditions.
Use water trailer with take from surface storage [Founders' Lake].
Generally our plants will survive short dry periods. However, we only have one irrigation pump and that can be repaired or replaced very quickly. If we run out of water there are alternative sources of supply for small volumes to keep specific plants alive until conditions improve
Truck the water in and hand water the heritage listed trees as a priority. Remove lawn watering first.
We have water carts for to tow behind vehicles
on site water storage tanks
Water carts / manual hosing of collections and we have a water supply from a pond system that can be harvested also - pond water can be drawn into a 120,000 litre tank on site for irrigation.
River water licence has been approved for emergency use, as our tertiary water supply if needed.

Q1.18 - Do you have any other comments to make about the preparedness of your garden for water shortages or water restrictions?

No
It is an issue that remains a priority during and in between water restrictions and availability. Out focus is to deliver the most effective and efficient method of water delivery to our diverse living collection containing over 6000 taxa but ensuring we do so without losing valuable plants from the collection.
Our biggest challenge is that we manage a garden which has a collection dating from 1851 and as such many species not ideally suited to local rainfall conditions and requiring irrigation. Approx half of the garden requires ongoing irrigation to maintain the collection.
The majority of our collection will survive such a shut down. The ephemeral ones that will not survive this are all kept as seed in our seed bank so we would grow more when the water returns. The chances of any water shut down lasting more than a day or two are very remote and most of our collection will last at least two weeks without water.
careful monitoring of water use at certain times of the year always takes place.
no
We're trialling grasses that are better adapted to dry times
As previously stated the nature of our collections makes a water shortage less of a threat to our collection as does the large artesion reserve of water estimated at about 300 years supply with other reserves available when that one runs out.
We recognise that rainwater harvesting and storage is critical to our ability to managing our collections during periods of water restrictions and are working towards developing this system further.
We have regular dry spell around August so gardens are well watered,then mulched in excessive dry times dripper feed irrigation is used
Transition the palette of plants so they become less reliant on irrigation and are more resilient to the future climate
We have a new shelter built that has a large roof space. I think it would be a great idea to capture the rainwater and store it in water tanks.
Our problem is flooding of specimens
As stated earlier, in 33 + years we have not had a problem with lack of water and in this time we have had severe droughts.
Gargarro is in the very early planning stage. However we are in the fortunate position of owning a substantial water entitlement which will provide a source of revenue in years of plenty and be sufficient for the needs of the garden in periods of scarcity.

Average rainfall is 1800 mm thruout the year. 7 ponds. Gravity feed.
Plant selection Mulch and fertiliser
We are moving to mulching mare surface rooted plants.
See above - while we don't have documentation about water shortage responses, all involved understand our Gardens and know what to do in these circumstances
We've had recycled water irrigation for 8 years now, so the garden has reversed it's history of having to truck in water. If it goes back to the way it was, our garden will just have to replace plants with those that don't need irrigation. We'd lose a lot of plants before the changes were made, but the heritage trees we have remaining are the ones that survived the last drought, and would probably survive the next.
Long term we are changing beds to capture and store as much water in the soil as possible
water is primarily sourced from the aquifer via 7 bores. these are managed inline with licensing restrictions and should be maintained over time to continue to supply water.
Mulching and tree root zone protection program continues.

Q2.1 - Where is your garden's water primarily sourced from?

Answer	%	Count
Municipal water supply	31.43%	11
River or stream	2.86%	1
Ground water	17.14%	6
Surface water harvested and stored in a reservoir	20.00%	7
Desalination	0.00%	0
Other	28.57%	10
Total	100%	35

Other
Lake Burley Griffin
municipal water and stormwater
Irrigation entitlement from Goulburn Murray Water, a rural water authority.
combination of Rain and Ground water
Evenly shared between Municipal water and river
rain
Recycled water
Lake on site
recailed sewarage water
Bore water

Q2.2 - How much water does your garden use each day to irrigate its outdoor living collection?

Answer	%	Count
Quantity:	62.50%	20
Don't know	37.50%	12
Total	100%	32

Quantity:

maximum use is 2ML per day in height of summer
500kl
variable depending on season. You'd be better to ask annual irrigation delivery.
just over 200,000 litres
15,000L
approx 900 litres
130ML per year
Not applicable
summer peak 70kL, yearly average 33kL
1 Million megalitres
nil
varies due to seasons.
We only irrigate our softer plant(ferns and some rain forest plants)
Approx 10,000 litres
27 ML/Year
4mg/l
1 mL
100,000 litres summer
200kl
0.2mgl

Q2.3 - How much water does your garden use each day to irrigate its glasshouse living collection?

Answer	%	Count
Quantity:	51.61%	16
Don't know	48.39%	15
Total	100%	31

Quantity:

1500 litres
variable- currently dont separate out stats to know as part of overall nursery operation
1200 litres
5,000L
100 litres
3kl
Not applicable
0kL
1.75ML
no glasshouse
< 100 L
We have no glass house
Approx 200 litres
0
150litres
500 litres

Q2.4 - Describe the type of irrigation mainly used in your garden? For example, is it an automated system, portable hoses, drip irrigation, sprinklers, hand-watering, or some combination?

Fully automated system with a combination of sub surface drip irrigation and sprinklers. Hand watering of newly planted specimens also occurs as a supplement.
All of the above
garden: automated, hoses, spot handwater, leaky hose around mature trees Nurseyr; primarily handwater, drippers for advanced tree stock
Across the outdoor areas - drippers 4 litres per hour (60km of dripline and about 60,000 drippers). Glass houses and nursery- opposable sprayers 3 litres per minute
Automated with over head sprinklers
combination but very little drip irrigation
drip irrigation on an automated system for the garden. Micro sprayers in the glasshouses and
A combination of automated and hand watering
Combination of hoses,sprinkler,drip and hand water
fully automated
Automated system, hand-watering, water tanks on trailer filled by water mains or by tank water. As well as an underground water tanks connected to storm water captured thru a rain garden that leads into a man made lake.
sprinkers, trickle mostly automated
Combination of sprinklers, hand held hoses, and mist irrigation in the Propagation house.
No infrastructure yet, but planned to be an automated drip system.
Drip irrigation for plant collections. Automated pop-up sprinklers for turf
Mixture of automated sprinklers and manually operated sprinklers
Computer controlled system operating half drip and half sprinkler systems.
Automated watering, drip, bottomup and handwatering
portable hoses, flood irrigation, RAINFALL
Automated system and hand watering of newly planted stock during summer.
Water efficient sprinklers, drippers and hand watering.

Automated sprinklers and some hand watering.
Sprinkler at fixed points or on hoses run for 12 or 24 hour periods once a month in summer provided soil moisture is not naturally replenished.
Automated in ground drip system outdoors, automated misters indoors
Automated sprinklers mostly
portable and drip
fully automated linked to soil moisture sensors and weather radar
Mix of portable hoses and irrigation, approx. 80% of water sourced is potable.
90% automated sprinkler irrigation
Computerised irrigation with as needed sprays/hand watering in peak times

Q3.6 - What is the total annual budget of your garden?

$22 million
Approximately 2 Million dollars (AUS$)
$5,254,000 Aus
$3.6M
AU$2,300,000
$3,000,000 AUD
$100,000
$5m just for the Melbourne Gardens division
Approximately $320,000
$100k
Planning stage only, no annual o&m budget
unknown
1.3 million
$4M
$4000
$150,00 AUD
A$50,000
$430,000.00
Three hundred thousand dollars
$100,000.00
Approximately $AUD50,000
confidential, but not much
$390,000
$1.4m horticulture only
$3.5m (operational)
$3.2m
$700K

Q3.7 - How many full-time equivalent positions (FTE) positions are there at your garden?

135 - includes all agency staff - corporate, administration, education, research and grounds staff
Living Collections 23
10
7 admin, 3 cafe, 10 Horticulture (Botany Dept), 6 Professional Guides, 15 keepers (Zoology Dept). Note we are an acredited Botanic Garden with around 95% vouchered specimens with known wild origin (GPS co/ords included) and also have a zoological collection housed within our botanical habitat based collection.
42
27
29
2
50
3
4
Volunteers put in approx 500 man hours a month
nil
2
15
24
45
NIL
1.5
4 - 5
4
One Horticulturalist plus volunteers from the Friends of the Garden

3
0.5
3
4
12 horticulture only
22.5
19
6

Appendix C

TABULATED SURVEY RESPONSES

Comments on Strategies to Manage Water Shortage

Table C.1 Qualtrics Q13 **UNITED STATES** Descriptions of Strategies to Manage Long-Term Water Shortage Sorted by Theme and Separated into Individual Actions

Q1.13 Please outline how your garden will manage its living collection in the event long-term water restrictions	
Use drought tolerant plants & regional taxa	**4**
We are planting more native, drought tolerant plants.	
One of the criteria for the collections is regionally adapted plants. If significant, repeated droughts occur, it is part of the selection process for the garden. If the same taxa dies repeatedly in response to the same stress, it is eliminated form the collection.	
Partially reduce the number of containers in the garden and, for the most part, choose more drought tolerant varieties, like Pelargoniums (geraniums).	
Plant begonias, which are drought tolerant, in several annual beds.	
Heavy mulching	**1**
This coupled with soil building practices and woody mulches, many plants are buffered against drought, to an extent.	
Prioritize watering important collections	**2**
Impose a moratorium for new plantings and transplantings.	
If our 4 year drought continues to a fifth year we will need to start prioritizing within the individual collections. We have many succulents, which although are suffering, are surviving. Our cycad collection will always receive the water it needs.	

Prioritize watering important woody collections	**4**
Water will first go to trees and shrubs to keep them alive. Any water left will then go to turf and annual flowers.	
We manually irrigate select garden plants in order of priority: / Trees (that aren't drought tolerant) / Other woody plants i.e. shrubs and vines (that aren't drought tolerant) / Misc plants that would be extremely difficult to replace / T&E plants particularly if not waterwise / We would accept the loss of herbaceous material, unless it rare or extremely difficult to replace.	
Topiaries and state champion trees will be given priority. larger trees and shrubs will be irrigated as needed. Most native trees and shrubs will be allowed to go dormant as long as they are established. Evaluation of seasonal bed areas and containers to decide which not to water. Most turf areas allowed to go dormant. /	
Water bags for young and important trees /	
Reduce or eliminate turf watering	**4**
We have removed all unnecessary lawn areas,	
Lawn reduction, first, conserving water for heritage trees and shubs.	
Even though we have our own water source we have self-imposed restrictions - we have let the "great lawn" die and many peripheral trees, hedges, etc.	
Allow many low-visibility lawns to go dry for the summer. Currently planning for 40% (40,000 sq ft) of turf to receive either no or reduced irrigation.	
Sacrifice display beds & replaceable plants	**1**
Reduce potted plants for color display	
Stop watering and let nature take its course	**2**
Irrigation removed during the summer months stage one, removed altogether in next stage.	
Let nature take its course.	

Survival watering of drought tolerant plants	**3**
Many of our plants in the collections, such as palms, have been "trained" for drought by receiving deep and infrequent watering to encourage deep rooting.	
Irrigate woody plants at 40% of normal levels.	
Refrain from irrigating olive orchards, blue Atlas cedars and other stands or woody plants normally receiving monthly summer irrigation.	
Have, or plan to drill, high security bore water	**2**
Our area is currently under water restrictions. We, luckily, have our own water source (well/aquifer) and just successfully completed digging a second well. Our first well is more than 100 years old and has never failed, but the water table was dropping to an alarming level.	
We are looking at drilling a well which is not restricted.	
Increase infiltration, store water directly in soil	**1**
increase stormwater infiltration,	
Increase water harvest & new storage on surface or in aquifer	**2**
To do this, we need to build more storage capacity, to maximize our water collection,	
We will be restoring garden infrastructure and plantings within the next several years. New irrigation will include water catchment / filtration system designed to re-use runoff as irrigation water.	
Install edaphic monitors & efficient irrigation	**5**
and improve efficiency of irrigation.	
we had water and use soil probes and meters to measure the need for water.	
increased monitoring of irrigation needs for more effective use of water	
The new (irrigation) system will be computer controlled, low flow.	
We have switched to even more drip systems and creative, low-use watering methods.	

Rely on backup stored water - ponds, dams, lakes	**3**
We can pump from a pond on-site.	
We have a back up pond for the collection and we are also on municipal water system.	
We have constructed a backup reservoir and also have pumped water from our main lake into the irrigation lake to keep it operational.	
Use external recycled water	1
Still in the planning process to expand the reclaimed water use on the property. This source of water is not restricted in a drought.	
Not Classified	3
NA - our collection is stored in vitro	x
Botanic garden and entire state has had and will continue to have severe drought conditions. This is a perpetual problem here and one that causes great concern for the garden, city and entire state.	x
We have our own water source and our long term plan is to limit irrigation to water from our own source, rather than using purchased water.	x
Total Number of Actions not including marked ‘x’	**32**

Table C.2 Qualtrics Q13 **AUSTRALIAN** Description of strategies to manage long-term water shortage sorted by theme, and separated into individual actions

	4
Change plant palette to plants which don't need irrigation	
Using local native plants reduces water usage significantly. /	
dry tolerant plants are selected	
Please note that our 'living collection' is located in a desert and only consists of species from this desert therefore most plants, but not all, are highly drought resistant.	
Heavy mulching	**1**
Gardens are heavily mulched,	
Prioritize watering drought sensitive plants	**1**
others enough water to maintain plant health /	
Prioritize watering important collections	**1**
Internal water rationing program developed with key areas maintained and lower graded areas gradually reduced or stop water.	
We have a strategy that adopts the principles of triage actions as the level of restriction, threat escalates / priorities for water application relating to the capacity of the collections to / tolerate lower soil moisture levels /	
Prioritize watering important woody collections	**2**
Tree collection is first priority, important shrub collections second	
1. Established / significant trees to be priority no.1 in relation to irrigation allocation. / 2. The remaining living collections take next priority. /	
Reduce or eliminate turf watering	**4**
turf areas to be maintained in drought, allocated as 15% of total turf area.	
The gardens will review irrigation practices across lawn .	
3. Allow lawn areas to 'brown off', if necessary. The lawn areas would become the lowest priority.	
Turf areas are ranked according to priority for water use. Turf areas have been identified as potential areas for further reductions or shut down if water availability is further reduced.	
Sacrifice display beds & replaceable plants	**2**

As per previous statement - we have identified 'sacrificial collections' to ensure water is used on our most important collections. Sacrificial collections are display beds, and collections that can be readily replaced.	
The gardens will review irrigation practices across non essential amenity displays	
Stop watering and let nature take its course	**1**
To meet budget demands we have turned water off to sections of our garden that are not part of the public area and that consist of highly drought resistant species	
Survival/deep watering of drought tolerant plants	
* Some collections considered to be more drought tolerant will receive minimal irrigation,	
Current garden bed water management is at a minimum application rate allowing the plants to adapt to restrictions. /	
Bore system to augment other water supply	**3**
Bore system installed and maintained. Legally cross connected to town water ring water-main system, with separate potable drinking water system.	
as well as a reliable bore.	
Botanic Garden has an independent water supply . This is rain catchment and supplemented from several bores. While we have an annual allocation this should be sufficient into the future. This was a plan developed from the inception of the garden in the 1950s.	
Expand on-site gray water recycling	**1**
We are in the process of installing a system to recycle grey water (sewerage) back into the water thirsty turf. This will reduce the draw on our only dam.	

Have, or plan to drill, high security bore water	**1**
We are also blessed with a large artesian basin supplying us with water so we have never suffered water restrictions. The cost of water is another matter with this going up a factor of ten times of the last few years.	
Increase infiltration, store water directly in soil	**1**
Mitigation and harvesting.	
Increase water harvest & new storage on surface or in aquifer	**5**
Storm water harvesting possibilities explored and approval process in place if needed.	
The construction of the first Creek Wetland and aquifer storage project is aimed at future proofing the gardens water requirements.	
A stormwater harvesting project - Working Wetlands was implemented to harvest water from surrounding streets and store in our lakes system, it can then be pumped into our irrigation system, offsetting potable water use by 40%.	
Our Strategic Planning Framework highlights the need for an additional dam to be installed to cover the site's needs into the future.	
Stormwater harvest dam has been built to reduce the ongoing reliance on potable water /	
Install edaphic monitors & efficient irrigation	**2**
New irrigation system being installed which is more efficient in delivery and can use either potable or recycled water. System able to deliver water by water use zones. /	
and method of water application	

Rely on backup stored water - ponds, dams, lakes	**4**
We can change from potable water to stored water	
We have a large water reservoir on site	
Onsite water sources	
plans have been implemented to irrigate the collections from overflow lakes that have been constructed as part of a redevelopment.	
Truck water in	**1**
Water trucks,	
Use external recycled water	**2**
Expansion of recycled water system as budget allows.	
& recycled water	
Acquire high-security 100ML irrigation license	
Planning is underway to use 100% sustainable water for irrigation and become non-reliant on potable water.	
Cultivate great relationship with water supplier	**2**
We also have an excellent relationship with our water wholesaler and retailer that assists when exemptions to restrictions are possible.	
The draft Living Collections policy and operational plan now features water conserving and using water efficiently as a priority. / And since the impact of the drought the ANBG has applied a pro active approach to innovative and strategic focus on water management. / this includes enacting regular meetings and engaging with stakeholders to determine and implement the best strategy / for the circumstances.	
Total:	**43**

Table C.3 Qualtrics Q13 **AUSTRALIAN** AND **UNITED STATES** Long-term water shortage plans collated and sorted into themes.

Actions Within Plans U.S. n=23, Aust n=20	U.S.	Aust
Collections Theme		
Use drought tolerant plants & regional taxa	3	4
Horticultural Theme		
Prioritize watering any important collections	1	2
Prioritize watering important woody collections	4	2
Prioritize watering drought sensitive plants	0	2
Survival watering of drought tolerant plants	2	2
Sacrifice display beds & replaceable plants	2	2
Reduce or eliminate turf watering	4	4
Stop watering and let nature take its course	2	1
Heavy mulching	1	1
Subtotal:	15	16
Water Theme		
Increase infiltration, store water directly in soil	1	1
Use external recycled water	1	2
Expand on-site gray water recycling	0	1
Install edaphic monitors & efficient irrigation	5	2
Increase water harvest & new storage on surface or in aquifer	2	5
Rely on backup stored water - ponds, dams, lakes	3	4
Have , or plan to drill, high security bore water	2	1
Bore system to augment other water supply	0	3
Truck water in	0	1
Subtotal	14	20
Policy and Relationship Development		
Cultivate great relationship with water supplier	0	2
Acquire high-security 100ML irrigation license	0	1
Subtotal	0	3
Total Actions	32	43

Table C.4 Qualtrics Q14 **UNITED STATES** challenges when developing a plan to manage long-term water shortages

Knowledge of What/ How to do it	
I'd say main concerns have been how to adopt/implement water conservation practices	1
Financial	5
Cost and	
funding	
including funding of accessing and	
installing more and more water efficient systems and practices,	
Added expense	
Selection and Sourcing Plants	1
Native plants are not easily available in mass quantities in our location.	
Inability to Carry out the Plan	2
If the water shortage is the result of an earthquake, and subsequently major waterlines, we may not have access to water to implement the plan.	
I don't believe we have the in-house equipment and materials to utilize our new reservoir yet but will have to during any future drought like 2006 or 2012.	
Politics and Policy	5
Using recycled water, funding all of these and . of special needs for the garden during times of various stages of water restrictions.	
keeping our plan consistent with other (city and state developed) drought response plans	
regulations governing reclaimed water use	
Athletic fields used for university sports were not included.	
working with city and various water utilities orgs City has never solved the water shortage problems to everyone's needs; extremely political issues to deal with and getting some exceptions to water usage is always difficult but so far city realizes the garden is a special case. I think our popularity with citizens and tourists has helped us a lot with special needs.	
Staff time, training and buy-in	2
and staff time,	
staff retraining,	
Public support for Visual Changes	4
More so internally in having to decide how conserving we wanted to be. In the end, we struck a good balance so that our guests would not be impacted by the value of their admission and still doing our part.	
Saying goodbye to some thirsty plants that would not make it through.	
Yes, objection to lawn replacement and loss of functionality of lawn areas	

loss of lawn space	
No Challenges	**5**
No	
no	
No to date.	
No	
No.	
Total number of challenges recorded	**20**

Table C.5 Qualtrics Q14 **AUSTRALIA** challenges when developing a plan to manage long-term water shortages

Financial & Infrastructure Costs	**8**
Budget.	
Funding for replacement refurbishment of pumps and delivery lines etc.	
Plenty, funding, construction,	
only financial	
yes, financial	
Some infrastructure upgrades	
* cost of infrastructure /	
yes- financial implications	
Selection and Sourcing Plants	**1**
Plant selection is critically important, the hardest part is convincing others who don't understand the limitations on plant selection. It's political to say to some in local government circles that we won't be replanting high, water use, heritage plants such as Elms, Pines, Willows and Poplars and will be replacing them with Oaks, Dry climate Pines and other trees that may not have been planted on the site before. Many in the nearest main city of Melbourne, still don't understand how hot and dry it is in Bendigo compared with Melbourne. (2 hour drive away, but half the rainfall, and more extreme temperatures in Bendigo)	
Adapting Trees to Use Less Water	**1**
The most critical challenge is the relationship between the trees living in turf areas and working out how best to manage the trees to adapt to less water. / We have adopted a transitional reduction in many turf areas to try to drought proof the trees should additional water restrictions be imposed.	
Politics and Policy	**1**
Comprehensive consultation process and bore water table levels are diminishing progressively.	
Staff time, training and buy-in	
operation. Having dedicated staff in this area is a must.	2
retraining of staff to use new irrigation system and now focusing on developing a greater understanding of plant water requirements	

Public support for Visual Changes	**3**
No - it has not yet been required to implement the plan, this will certainly cause disruption to service. / For example: Wollongong has a number of display beds in high use parts of the garden that will be the first collections removed under extreme water shortages.	

Never implemented, fairly confident that senior management do not recognize the impacts if ever implemented.	
The general consensus amongst staff was that this was the right thing to do. The most difficult issue to deal with is getting the public on board as they love our lawn areas and many of them object to these areas being allowed to brown off. It takes quite a bit of careful PR work to keep everyone informed.	
No Challenges	**4**
No	
Not really	
No as the it was simply a matter of selecting areas to turn water off too. These were self evident.	
Not really, we collectively pooled our expertise and sought advice from external specialists and regional institutions to collaborate on the best outcomes.	
Total Number of Challenges recorded	**20**

Table C.6 Qualtrics Q15 **UNITED STATES** barriers to developing a plan to manage long-term water shortage

Q1.15 Are there challenges and barriers that prevent such a plan being developed and implemented?	
Staff and Time Constraints	**17**
Staff number and time availability	
The time to get it completed.	
Time, personnel - all the usual	
Just the time to do so.	
Not having a staff person to dedicate time for such a project. Really do not have a registrar to record data on a regular basis. Our garden has primarily been a display garden and in recent years more of a rental facility for weddings, etc. We also focus on entertainment, such as a summer concert series, wine tastings, etc.	
We have not had a full time curator on staff.	
Daily time constraints	
I am tasked with updating the entirety of our garden.	
A plant collections management plan has been in early stages of development for several years, however limited resources	
Too many acres, not enough staff,	
No, just the usual time restraints	
Staffing, knowledge of the issue, and time	
We are a new botanic garden and have not had the staff time to develop these plans	
Yes--lack of volunteer resources.	
Time restrictions of the current staff	
Human resources to develop the plan and	
Time	

Other Priorities	11
Because the threat of drought or water restrictions is not big in our part of the country, there is not much motivation to complete it when the "to-do list" is so long.	
Ample rainfall over the past 2 growing seasons has lessened the urgency factor although we should address this in our Master Plan.	
It will take time before I can get to this plan because water issues are not our greatest threat.	
The will to make a plan. Short term thinking keeps us focused on the immediate needs. Strategic plan is only five years out, and makes no mention of water issues.	
The arboretum is not a primary function of this college. There are other priorities.	
Other financial priorities have thwarted progress.	
No. However time spent to develop such a plan must be weighed against practicalities: a drip irrigation system is in place, and annual rainfall exceeds 55 inches.	
No, it just hasn't been a priority (or even discussed).	
We have few people and many projects, plans and policies that are all good ideas that we 'should' do. but we can only accomplish so much.	
Water restrictions are rare in our region so this issue is not top of mind.	
many more pressing issues need to be dealt with (and are not) for this reason.	
Budget	**1**
The cost of drilling wells - very expensive, and you might not even hit water; time with limited staff to develop a plan that may or may not ever be useful	
External Planning, Management or Legislative Issues	**3**
We have a long term lease on County land and share water lines with the surrounding County Park. Our water use is not managed separately from that County Park, although we use water conservation methods at our botanical garden.	
Our relationship to central campus is somewhat poorly defined. We are currently in negotiations about how campus would provide water in the case of an catastrophic natural disaster (in our case, earthquakes/slides, and wild fire.	
manage the relationship between the city department and the non-profit partner.	

No Need, Plants are Drought Adapted	**1**
No. In the case of the University of Georgia, extreme drought periods several years ago led to a complete ban of drip-line irrigation of on-campus gardens. The impact was minimal for this collection. Heavy use of mulch has allowed most plants to survive well and we have opted to only use spot watering when necessary, even after the "drought" period ended. The vast majority of species maintained in this garden are highly durable perennial species once established and we also maintain a large collection of arid species.	
Secure and Reliable Water Supply	**8**
Being in east, it is not so much restrictions as access. If pumps or elec failed or some catastrophic event. / We are working on incorporating plans to have water available, either stored on sight or tanker trucks.	
We have onsite wells and available water nearby. The drought has larger impact daily and through heat in the air than on water restrictions.	
No - we are on well water, so the local watering restrictions don't apply to us. But, our practice is to only irrigate to establishment, and we are not concerned about restrictions for the permanent established collection.	
No. We are on a lake with the ability to pull from the lake or use city water. We prefer to draw from the lake due to the cost of city water for irrigation.	
Developing a plan is not a priority since we have our own source of water.	
We are fortunate through our location in New England (Western Massachusetts) in having enough precipitation most summers and in having two deep wells, which have not run out during the last 25 years, for watering the gardens as needed.	
right now too much water has been more of an issue - quick drenching thunderstorms as well as springs popping up.	
We use well water exclusively so are not restricted during droughts	
Other	**8**
Developed, no. Implemented, none other than trying to prevent plants from dying should restrictions be severe.	
We have wells on the property that we would like to use, but dissolved iron and manganese in the water stain structures and plants when it is used. Inexpensive treatment is needed to address this problem. Until then, we are using water from the municipal water works.	
i believe our regular management planning will be sufficient.	
No but it is a priority for the garden.	

No barriers. We have been switching to drip and low volume irrigation for some time. We have and are adding additional rain sensors to irrigation and electing to not install turf irrigation systems in parking and other low turf priority areas.	
1. We do have sub-collection specific disaster plans (as Bonsai - an outdoor facility, and Conservatory). / 2. We have consciously moved to reduce "general" irrigation and remove parts of the former irrigation infrastructure as un-sustainable. / 3. We will be revising (significantly) our collection policy this year, so these are good issues to raise. /	
Not sure how you can plan for such a thing, you have to respond to the situation at hand.	
No. My tenure goes back 30 plus years as a horticulturist in the Washington Park Arboretum and though we do not have a written water conservation policy based on collections care, we have substantially improved our water-use via more efficient irrigation systems (Rainbird MAXICOM) for newer exhibits and our new plant care team is more conscientious about wasteful watering. We rarely "blanket" cover all collections from summer rain regions and focus most of our watering on new plants (3 -year) program. We do have SOP's for irrigating manually - using the soil probe is our best method for determining if a plant needs water or not.	
No Barriers, Do not have a Plan	**6**
no	
None that I can see.	
No.	
No.	
No	
No	
Unclassified	**1**
While the City of Northampton may have water restrictions, it appears Smith is still exempt. Amherst (north of us) on the other hand cannot water their lawns (turf) when there are water restrictions	

Table C.7 Qualtrics Q15 **AUSTRALIA** barriers to developing a plan to manage long-term water shortage

Q1.15 Are there challenges and barriers that prevent such a plan being developed and implemented?	
Staff and Time	**2**
Time, staff	
There is currently not the resources	
Not a Priority / Not Important	**2**
Importance of	
There is not the interest or support from the higher powers in the organisation. Being Local Government there are many services they provide and the Botanic Gardens is only one. /	
Financial	**1**
Budget,	
External Planning, Management or Legislative Issues	
National Parks Plan of Management may pose issues?	1
No Need for a Plan, Plants are Drought Adapted	**3**
No. We maintain a collection sourced entirely from the arid zone in which the Bot G is located. Natural disasters are part of the living landscape here. Should they impact our garden the problem will be one of infrastructure rather than loss of plants as almost everything we have will grow back. Some rare plants are located in fire safe zones simply because many rare plants are those that live in moist environments and cannot be located in fire risk areas. / due to the nature of our collection restrictions will not greatly impact us. We use minimal water as it is. /	
No - our species are all plants native to our region and well adapted to hot, dry conditions; we typically only water them during the first two years	
and necessity. Currently our plants have to survive or fail through summer after 3 years although we may be about to review that given the rainfall outlook and climate modelling.	

Secure and Reliable Water Supply	3
Our water supply is also ground water and the reserve is very large ie estimated to last over 300 years by CSIRO scientists and then there are other reserves. We are still very water conservative and water conscious as 300 yrs is not for ever and we are conservationists in all ways.	
We have now installed reclaimed water irrigation to the gardens this allow us in time of water restrictions the ability to hand water the few plants that are sensitive to the reclaimed water. The reclaimed water is a guaranteed supply.	
Yes reliable rainfall. Abundant water supplies	
We use bore water to irrigate and the bore has not run dry in 30+ years. The one area of concern we have is the sale of water Commercially, to companies like Coca Cola for use in Mineral water. There is a fear that the amount of water being taken off the Mountain will effect the level of the aquifer. It appears that this has happened in other areas of the Mountain but so far we do not have any commercial bores that are adjacent to our Gardens.	

Table C.8 Qualtrics Q17 **UNITED STATES** Actions in the event of short-term water shortage

Q1.17 Please outline what your garden will do to protect its living collection in the short-term if the water supply is suddenly shut down?	
Pump from pond or lake onsite	5
If for some reason the rural water supply is shut down, we will be pulling water out of our two ponds to water plants/trees.	
Rain water harvesting system and irrigation from ponds.	
We could use our own water source to water plants, and if that failed potentially pump water from our artificial lake to keep plants that are irreplaceable. Plants would be prioritized according to our ability to replace them.	
lake water	
We have a pump system set up in a pond to irrigate with.	
Truck Water in and handwater	6
It will depend on the breadth of the shut down. If it is local to our facility we can truck water in. if it is a city-wide shut down, we have limited options.	
We also have water trucks available as well.	
We have a mobile water tanks and a supply of mobile irrigation devices.	
Use a water truck with water brought in.	
We would bring water in using partner organization water trucks, or utilize water lines connected to the County Park.	
We have a pump truck with a large tank that can be used to do some watering.	
Truck water in an pump through Irrigation system	0
Buckets/ Hand watering	3
Buckets! Some rainwater collection, though in drought conditions that would not be effective.	
We will hand water irreplaceable plants from our bodies of water.	
hand watering	
Fire Hydrant	1
Connect from fire hydrant to irrigation mainline in well house. Was done in 2006 when well collapsed.	
Hoses connected to distant water source	
We had a mainline break this year and had to tap into distant water sources using hundreds of feet of hose and sprinklers. If all water were out for the campus, we would have a lot more to worry about than just the plants.	
Pump from Stream or river	2
We may pull water from a nearby stream, however this will need to account for the needs of other creekside owners	

We irrigate 90% of our 80 acre garden with collected rain water. We also transfer water from streams bordering our property.	
Pump from backup wells or bores	2
We have redundant systems with back up wells if needed, which have an established order of use depending on water quality (salinity).	
We have 4 separate well systems set at varied water tables and areas of the property. they are on different power systems. We also have availability to have a tank delivered if vital but have never come close to this need.	
Backup Pumps & Generators	
City water backup	3
We rely on gravity system, some of which is 100+ years old to supply much of our outside irrigation. We have back up tanks and potable systems to use in emergency situations. For the conservatory, we use potable water system and can back up with old system.	
We have a redundant irrigation system and city water backup and also cisterns in some cases.	
We have the ability to switch back and forth from lake water or city water.	
Cistern / tanks	3
utilize cisterns and	
We do have a 10,000 gallon cistern that collects water from the roof of our greenhouse complex. This water would allow us to maintin the plants inside the greenhouse and in nearby nursery/growing areas for a period of time.	
We presently have a 1,000 gal. water cistern and are constructing two more, which capture water-runoff from building roofs and store it. The irrigation system is being designed to tap into those sources should the irrigation wells malfunction.	
Alternative Water Supply, not specified	1
If water is suddenly shut down we have a prioritized list of water-sensitve and irreplaceable (often endangered or threatened) plants we will focus on in the short term.	0
Use drought tolerant plants	0
Increase Soil Water Holding Capacity	0

Table C.9 Qualtrics Q17 **AUSTRALIA** Actions in the event of short-term water shortage

Q1.17 Please outline what your garden will do to protect its living collection in the short-term if the water supply is suddenly shut down?	
Pump from pond or lake onsite	**6**
Use water trailer with take from surface storage [Founders' Lake].	
and we have a water supply from a pond system that can be harvested also - pond water can be drawn into a 120,000 litre tank on site for irrigation.	
(Bores and) lakes in the garden can be linked to the irrigation system	
The Wetland aquifer storage system - The lakes can be used to pump water to key collections	
Use our stored lake water and we have a full time plumber, qualified irrigation staff and technicians available at short notice to deal with any infrastructure issues.	
Use of the stormwater harvest dam which is connected to the irrigation system. /	
Truck Water in and handwater	**5**
Water carts / manual hosing of collections	
We could also use our water tank to cart water in from other areas and hand water.	
Truck the water in and hand water the heritage listed trees as a priority. Remove lawn watering first.	
We have water carts for to tow behind vehicles	
Water sensitive species and for our propagation facilities we would transport water in and hand water.	
Truck water in an pump through Irrigation system	**1**
Transport of recycled water to site tanks which can then run through the irrigation system.	
Buckets/ Hand watering	**0**
Fire Hydrant	**0**
Hoses connected to distant water source	**0**
Pump from Stream or river	**1**
River water licence has been approved for emergency use, as our tertiary water supply if needed.	
Pump from backup wells or bores	**1**
Bores (and lakes)in the garden can be linked to the irrigation system	
Backup Pumps and generators to replace electricity supply	**1**

There are several backups including a diesel pump and a Diesel powered generator to replace electricity . / These are the issues that will have an impact on supply. There are also battery operated Automated systems on the most valuable parts of the collection that may be impacted by extended periods of garden closure due to high fire danger ie when no staff are present either.	
City water backup	**3**
on-site water supply & ablility to use pottable water if our irrigations pumps fail	
we will get the problem fixed, but we can switch over to the mains water temporarily and run the system manually.	
There back up supply sources, such as recycled water and multiple meters that can supply water across the garden. / . /	
Cistern / tanks	**2**
We have an underground water tank that stores stormwater runoff. It holds152,000 litres.	
on site water storage tanks	
Alternative Water Supply, not specified	**4**
However, we only have one irrigation pump and that can be repaired or replaced very quickly. If we run out of water there are alternative sources of supply for small volumes to keep specific plants alive until conditions improve	
We don't use water from off site. /	
It depends on the scenario length of time, weather and alternative supply options, all of which are discussed if this scenario eventuates.	
We have an alternative water supply and back up pump station in the event of failure of the main groundwater supply. / / The nursery has both scheme/mains water and a ground water supply, also with the back up pump station and alternative water supply source.	
Use drought tolerant plants	**4**
Once again dry tolerant plants are selected	
Use adaptable native plants that will tolerate these conditions.	
Generally our plants will survive short dry periods.	
Most of the collection will survive for a number of weeks without water so there is little or no risk there.	
Increase Soil Water Holding Capacity	**1**
We have a regular mulching program and using wetting agent every time we plant. This helps reduce water loss and increases the soil's water holding capacity.	

Appendix D

ROYAL TASMANIAN BOTANICAL GARDENS LIVING COLLECTIONS ATTRIBUTES

List of attributes developed by Royal Tasmanian Botanical Gardens to assess the living collection.

Class of Attributes	Attribute	Assessment Criteria
Defining	Regional	Collections with valid connections to our region; collections that are Tasmanian in origin (including Macquarie island); collections that are Australian in origin; collections that have a southern hemisphere distribution; and collections with Gondwana origins.
	Conservation	Viable potted and seed *ex-situ* collections; Collections of Tasmanian species that are listed on the IUCN Red List and/or under the Tasmanian *Threatened Species Protection Act 1955* and/or the Federal *Environmental Protection and Biodiversity Act 1999*; *ex-situ* potted and seed collections with a representative number of genotypes from within or between population/s; and collections of listed species in DPWI Threatened Species Recovery Plans.
	Botanical	Collections with scientific integrity; collections of known wild provenance; collections with detailed field collection records; collections with herbarium voucher specimens; and collections based on taxonomic principles with a comprehensive representation of taxa.
	Historical	Collections originating from or representing the heritage fabric of the Gardens or elements of Tasmania's botanical history; the mature canopy of trees originating from Victorian plantings; the Gardenesque Victorian elements in the landscape such as the palms; plantings based on records of early plant lists from the RTBG; and collections relating to Tasmania's botanical history.

Use	Interpretive	Collections currently covered by interpretive media other than plant labels; collections with in-ground interpretive signage; collections with associated pamphlets; collections interpreted in RTBG displays; and collections interpreted on the RTBG web site.
	Educational	Collections currently used for education purposes; collections used for the schools program; collections used for the community garden program; and collections used for Green Thumbs and Explore programs.
	Tourism	collections that specifically draw tourists to the RTBG; collections that are unique to the RTBG such as the Subantarctic Plant House and Tasmanian collections; collections of high ornamental value such as the Conservatory; and collections centred on events such as the Tulip Festival.
	Commercial	income generating collections; collections used as sites to for income generating activities such as weddings, naming ceremonies and memorials and other functions; and collections providing material for income generating activities such as plant sales.
	Spiritual	collections that have spiritual associations (Note: this attribute was not assessed due to the difficulty and costs of gaining information about reliable indicators).
Managerial	Horticultural	Collections with high amenity value; collections with strong visual appeal; collections displaying a range of horticultural selections; and collections that display current trends in horticulture.
	Site Suitability	Local environmental and artificial factors which influence the cultivation of collections; soil type and drainage; water availability and type of irrigation; slope and aspect; Local climate; adjacent plants; and adjoining infrastructure.

Appendix E

COMPARISON OF RETICULATED WATER COSTS

Water costs comparison between U.S and Australia. Currency is that of each country AUD or USD

Garden or County	Potable water cost /kiloliter	Annual potable water bill	Non Potable Water
Albury Botanic Gardens Country NSW	$1.83	$10,000 - $45,000	$200 for up to 35 ML per year Ground water.
Melbourne Gardens City of Melbourne	$3.1426	$74,287 - $260,00	N/A
Bendigo Botanic Gardens Country Victoria	$2.18	Not known	$1.66 / kiloliter (recycled)
National Rhododendron Garden Country Victoria	$2.83	$3241	$1100 for up to 9 ML per year
Wollongong Botanic Gardens Regional NSW	$2.276 per KL plus stormwater charge of $1.20 per KL	$100,000 - $200,000.	N/A
Royal Tasmanian BG Hobart 4" main	$0.97 per KL + $8237 meter charge	$60,000	
Miami-Dade County *Assumes a 4" main, Miami-Dade County non-residential rate at $3.343 per Cu Ft	$1.18 per KL* Plus $1293 per year Meter Charge.	Not Known	Not Known
Berkeley East Bay Municipal Utility District **Assumes 4" main, and $4.15 per 100 Cu Ft.	$1.46 per KL** plus $3015 per year Meter Charge	Not Known	Not Known
San Antonio TX *** Assumes 4" main, Landscape Irrigation Service Water $0.6329 per 100 gal.	Not Known	Not Known	$1.67*** per KL plus $2992 per year meter charge
Chicago ****$3.81 per 1,000 gal.	$1.006 per KL****		