January 2010

The nature of flooding

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Keywords
nature, flooding

Disciplines
Life Sciences | Physical Sciences and Mathematics | Social and Behavioral Sciences

Publication Details
Bourman, R. P. (2010). The nature of flooding. In C. B. Daniels (Eds.), Water of a City (pp. 52-53). Kent Town, South Australia: Wakefield Press.


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CHAPTER 2

The Variable Climate

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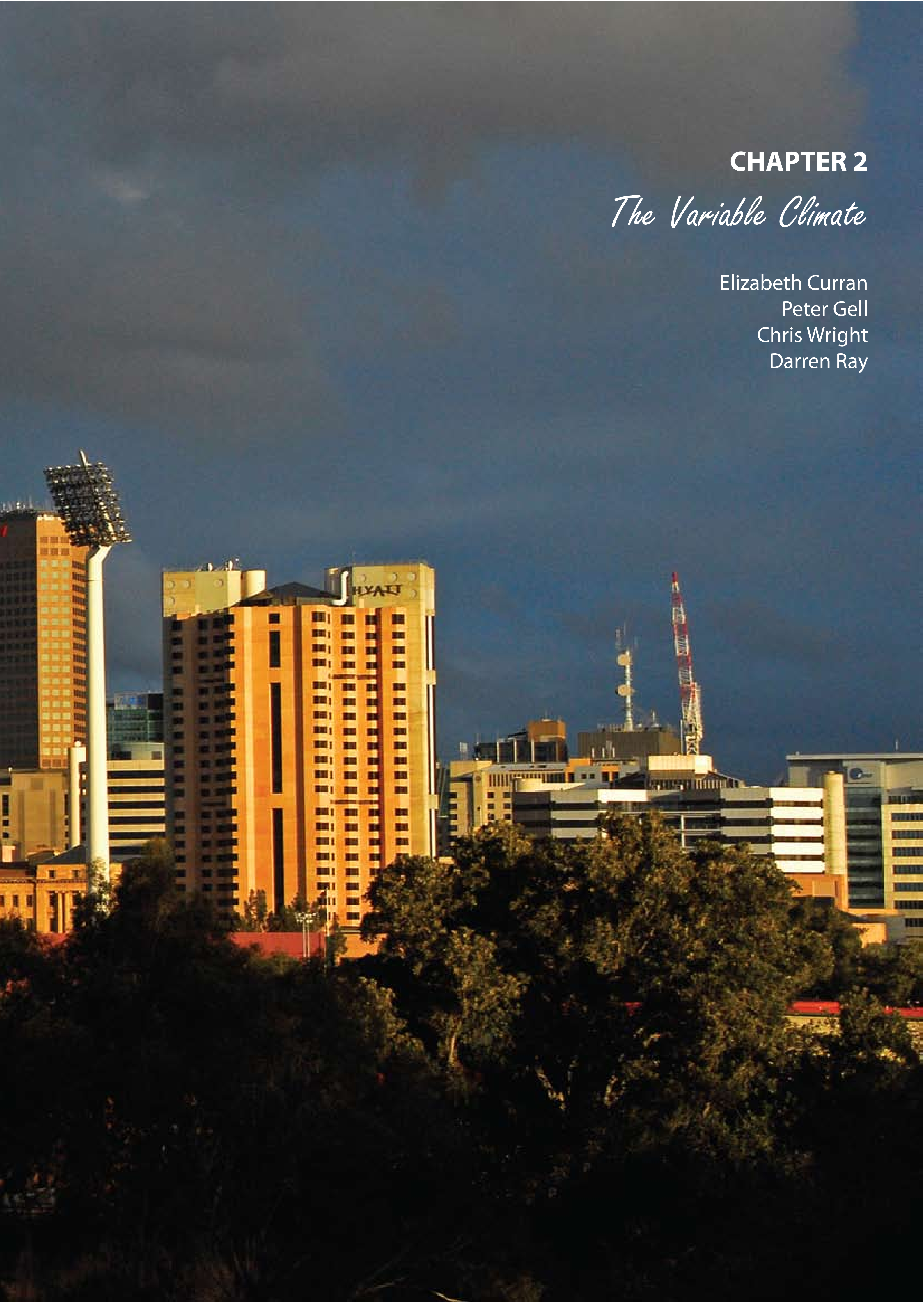


Introduction

The climate of a location is described by its temperature and rainfall characteristics, as well as other variables such as wind, humidity and evaporation, all of which have a significant impact on water resources. The story of climate though is incomplete without considering the causes, or major influences which determine local climate. Of prime importance are the atmospheric and oceanic general circulations, and the regional factors which impact on these. In the southern Australian region these impacts include sea surface temperature patterns in the Indian, Southern and Pacific Oceans, the Southern Annular Mode (SAM), which modulates the intensity and latitudinal extent of the westerly wind regime in mid and high latitudes, and the El Nino-Southern Oscillation which impacts on extreme climatic events in the Australian region. Other local factors such as proximity to the coast, topography, aspect and exposure and even vegetation type and other ground characteristics, are also important in determining smaller scale variations in climate and weather such as rainfall distribution, local winds and frost frequency.

People often ask how weather and climate are linked. Probably the simplest answer is to say that weather is what we experience from day-to-day, and climate is the synthesis of the weather over a long period of time. In other words climate describes the average or most common conditions, the extremes, and the frequency of specific weather events.

This chapter shows how the general atmospheric circulation drives the seasonal responses of Adelaide's climate and describes its key features including its natural variability and extremes. It includes a description of the weather patterns which have a significant bearing on the seasonal characteristics. Recent climate trends and potential future climate changes due to human activities, especially those activities resulting in increasing atmospheric greenhouse gas emissions, are also discussed.

Note: Unless otherwise stated, the mean statistics used in the text are from the Bureau of Meteorology's official observing site at Kent Town, just to the east of the city centre, where observations commenced in 1977. Extreme values may be from the Kent Town record or, if prior to 1977, from the West Terrace record, the official Adelaide city observing site until 1977. This site was just west of the city centre. Rainfall records were commenced in the vicinity of this site in 1839 and standardised temperature records commenced in 1888. Observing sites are selected to meet standard criteria to ensure they are representative of the wider locale.

Impact of the general circulation and weather patterns

The Earth's weather and climate patterns are driven by solar heating of the Earth's surface. Most of the Sun's energy is intercepted in the equatorial and tropical regions of the globe. This leads to a surplus of energy in the tropics and a deficit at the poles. The general circulation of both the atmosphere and ocean act to transfer excess energy from lower to higher latitudes.

Near the Equator, heating of the lower atmosphere causes large-scale vertical motion and convective cloud formation. As the air rises it expands, and commences its journey towards the poles, transporting both heat and mass away from the tropics. This upper outflow results in a region of low pressure at mean sea level known as the Inter Tropical Convergence Zone (ITCZ). The southeasterly trade-winds which prevail across northern Australia flow into this zone. As the upper air moves southwards in the Southern Hemisphere, it accelerates relative to the earth's surface and turns westerly in the fast moving subtropical jet stream. Of significance to Adelaide's climate, air in this region also sinks, returning to the lower atmosphere as the gently subsiding air of the subtropical ridge, a belt of high atmospheric pressure girdling the globe. The ridge occurs at much the same latitudes as southern South Australia, around 30° – 40°S.

General Circulation of the Atmosphere

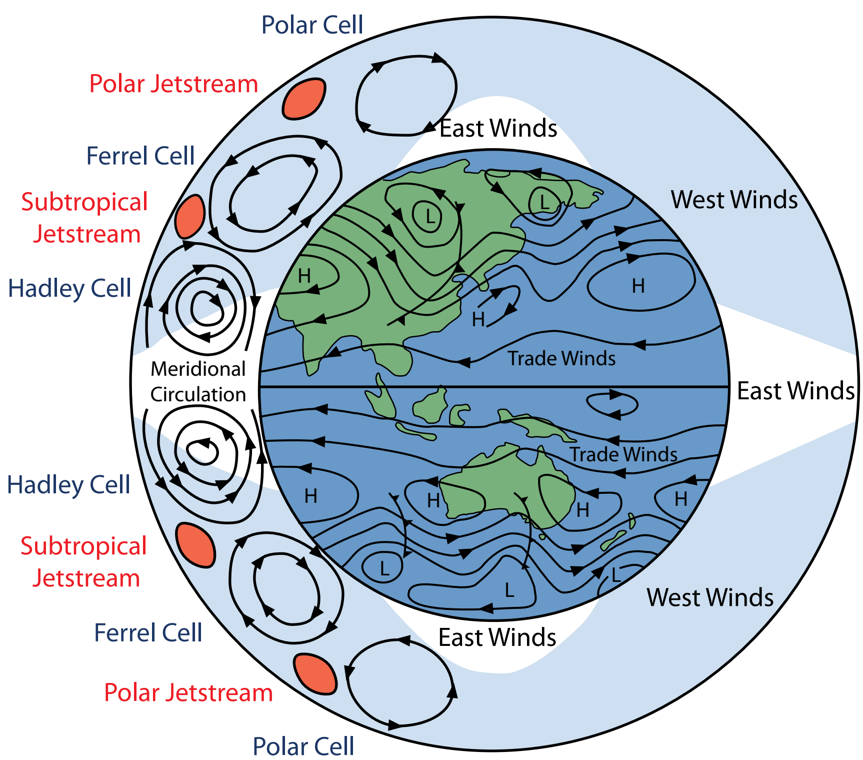


Figure 2.1 Main features of the general cirulation of the atmosphere showing the jet streams and cell structure of the meridional circulation transporting heat from the tropics to the poles. The Hadley cell, closest to the equator, and the Ferrel cell in mid latitudes, circulate in the opposite sense so that both produce subsidence in the region of the subtropical ridge.
Source: Bureau of Meteorology 2003

Does Adelaide have a Mediterranean Climate?

BOX 6

Mediterranean climates are characterised by dry, warm to hot summers and temperate winters, with a distinct rainfall maximum during the winter months. These are the general features of Adelaide's climate. Kent Town, with an average annual rainfall of 545mm, in most years receives less than 70mm in summer (December to February) while average winter (June to August) rainfall is around 220mm. Average rainfalls in the transitional seasons, spring and autumn, are much less than winter but still play a vital role in providing soil moisture for plant growth and resilience. Early European immigrants were quick to recognise the similarity of the new settlement's climate with those of countries like Italy. It is no mere coincidence that this is so, although our geography suggests, at least in terms of the temperature regime, lying on the Southern coastline of Australia, there may be a closer similarity with coastal locations on the southern shores of the Mediterranean, along the northern coastline of Africa. Other regions with Mediterranean climates include southwest Western Australia and California on the west coast of the United States.

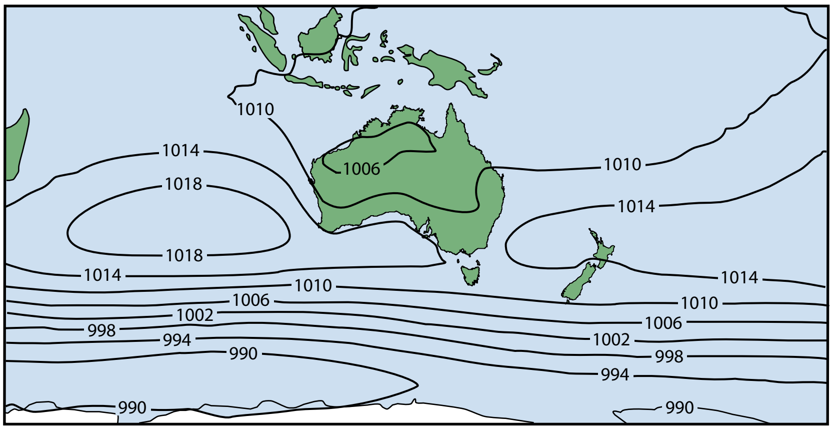
Like the Mediterranean, Adelaide lies in the mid-latitudes. At these latitudes, in both the Northern and Southern Hemisphere the distinct dry summers and wet winters are due to the impact of contrasting features of the general circulation. In summer the mean position of the subtropical high pressure belt lies in the midlatitudes (near 35 to 40 degrees latitude North and South) and the descending arm of the Hadley Cell brings stable and generally fine conditions. Clear skies and average daily temperatures in the mid–twenties, with maximum temperatures often above 30°C promote evapotranspiration, further reducing available water reserves in the soil. In winter, as the subtropical ridge retreats equatorward, these regions come under the influence of the westerly wind belt with its travelling weather systems. Reaching landfall after an extended journey over water, these frontal systems and accompanying moist unstable westerly streams bring the welcome winter rains. Forced lifting of the westerlies over coastal ranges serves to enhance the rainfall - an important ingredient in defining a Mediterranean climate.

It rarely drizzles in Adelaide. Mostly, rains tend to be moderate to heavy but relatively brief. Like other locations with a Mediterranean climate, we have about 90 raindays a year. (London and Paris which are not Mediterranean climates, have similar yearly rainfalls but have 250 -300 rainy days a year). In winter it is not uncommon for a front and accompanying moist stream to produce rainfall events of 30-40mm over two or three days. These events are usually separated by extended fine periods, often a week or longer. While less reliable, good rainfall events may also occur in autumn and spring. In fact, history shows it is the period from April to June when daily rainfalls are most likely to exceed 25mm. Average rainfalls in autumn and spring are very similar but in recent times autumn totals have declined slightly. The reason for this, whether it be climate variability, climate change or a combination of the two, is not clear. Infrequent short lived thunderstorms are responsible for most of the limited rainfall in summer.

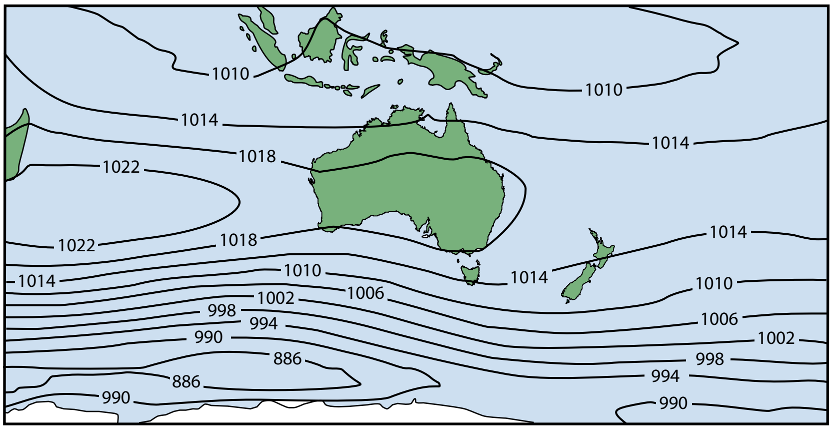
Adelaide's Mediterranean climate, makes managing water for gardens a challenge, especially in drought years. While the annual rainfall (an average of about 550 mm per year ranging to in excess of 1200 mm per year in the Hills and down to 300 mm per year at Semaphore) is reasonable, its distribution mainly in the cooler months, and its considerable variability from year to year requires careful planning to minimise water stress in summer. When late winter and spring rains fail this severely reduces soil moisture availability in the summer. High evaporation rates caused by hot summer temperatures and exacerbated by windy conditions add to the often harsh plant environment. Gardens well suited to Adelaide not only have deep rooted and drought tolerant plants, many of which may be of Mediterranean origin, but they are also designed to reduce soil moisture loss through evaporation.

Elizabeth Curran & Darren Ray

Mean Sea Level Pressure (mb)



January: 1950 to 2007



July: 1950 to 2007

Figure 2.2 Average mean sea level pressure for January and July showing the position of the sub -tropical ridge (STR) and associated high pressure systems.
Source: NOAA / ESRK Physical Sciences Division, Boulder Colorado, http://www.cdc.noaa.gov/

This large scale overturning of the atmosphere, from the tropics to the subtropics, is known as the Hadley Cell and is one of the most robust features of the atmospheric circulation. Two other meridional (ie between the tropics and poles) circulations assist in the transport of mass and heat between the Equator and the Poles. Figure 2.1 is a simple representation of these circulations. The Ferrel Cell, a smaller cell in mid latitudes contributes to the subsidence in the subtropical ridge and to the strength of the surface westerly winds in the mid latitudes, another important feature affecting Adelaide's climate. The third cell, the polar cell is important in transferring mass from the poles to the mid-to-high-latitudes, ie in determining the relative strengths of the pressure cells and zonal wind systems in this region. It contributes to the intensity of the SAM.

The latitudinal position of the subtropical ridge and mid-latitude westerly belt will vary, depending on the time of the year and day-to-day perturbations of the atmosphere, Adelaide's distinct seasons - its hot dry summers and cool wet winters - are largely a product of the mean seasonal position of these major features.

Fig 2.1: General Circulation of the atmosphere

Summer

During the summer months (December to February) maximum solar heating occurs in the tropics south of the Equator, and the mean position of the subtropical ridge lies south of Adelaide. The relatively cool ocean waters of the Great Australian Bight and the Western Pacific are preferred locations for the large high pressure cells making up the sub-tropical ridge. Adelaide's day-to-day weather during this season is largely determined by whichever high is more dominant (see Figure 2.2). Most commonly, this is the high centred in the Bight. Fresh sea breezes and overnight down-slope winds can occur under this regime in the Adelaide area, but otherwise winds are generally light. The southerly onshore stream keeps relative humidity in the mid-range and temperatures in the mid-twenties. Days are generally fine. Sea breezes along the coast keep coastal suburbs two to three degrees cooler than the northern and eastern suburbs, but these steady breezes also increases potential evaporation in exposed localities.

Figure 2.2: Mean Sea Level Pressure

On the flip side, when the Western Pacific high pressure centre anchors in the Tasman Sea and extends a ridge of subsiding air over Queensland and New South Wales, a hot, dry northerly stream prevails over Adelaide. This is a potential weather pattern for heatwaves. Once established, daily maximum temperatures in the mid to high 30 °C's are common, with each successive day a little warmer than the previous. In extreme events several days with temperatures exceeding 40 °C may occur. The sequence is broken by a front or trough moving in from the west.

Brief thunderstorms and showers may occur with summertime fronts but most often there is little cloud or precipitation. Rather, the frontal passage brings a sharp wind shift, the much awaited 'cool change' well known colloquially to Adelaide residents, and a return to a southerly stream as the high pressure rebuilds in the Bight.

Significant rainfalls in summer are generally limited to infrequent short-lived severe thunderstorm events. These require an infeed of tropical moisture. The most suitable conditions exist when a persistent trough extends south from Queensland allowing air, with high water vapour content (evident as high humidities) to feed into southern South Australia over several days.

Winter

In winter (June to August) the belt of maximum global heating lies in the Northern Hemisphere, shifting the southern Hadley Cell northwards. The mean position of the subtropical ridge now lies to the north of Adelaide, and the prevailing airstream is from the west. Travelling frontal systems in the stream are responsible for the generally reliable rainfall in these months. The Mount Lofty Ranges, running roughly perpendicular to the stream force the air to rise, enhancing the precipitation processes and effectively wringing extra rainfall from these fronts and moist air-streams as they move over Adelaide. It is common for rainfall in the hills to be twice the rainfall that occurs over the city, but this is not a hard-and-fast rule, and in some storm situations the rain along the coast could be greater than at Mt Lofty.

Many of the more significant winter rainfall events occur when moist tropical air is drawn into a weather system such as a northwest cloudband or a cut-off depression (cut-off low). The air originates over warm oceans and holds much more water vapour that does air originating south of Australia.

In a northwest cloud-band the moisture is sourced off northwest Western Australia. As the air moves southwards it rises gently, and as the pressure decreases the air mass cools. As it cools, and the humidity of the air reaches 100%, extensive bands of middle level cloud can form. Not all cloud-bands produce rain, but if the moisture and cooling are sufficient good widespread falls will result.

The frequency of northwest cloud-bands and cut-off lows varies greatly from year to year. Sea-surface temperature patterns in the northern Indian Ocean and in the mid-Pacific appear to be important in their respective development.

Cut-off low pressure systems that entrain moisture from the Coral and/or Tasman Sea have the potential to produce flooding. Divorced from the westerly belt, these slow moving systems can produce rain events lasting 12 to 24 hours - far longer than fronts travelling in a westerly stream. A widespread rainband, as well as convective clouds including thunderstorms with heavy downpours, can occur. While the systems are slow moving the associated winds can be fresh to strong and recirculate the moist air over Adelaide as well as entraining moist air from Bass Strait. Successive rainfall bursts can result. The cumulative effect of these rainfall bursts can lead to major flooding.

Widespread droughts brought on by failed winter and spring rains across southern and eastern Australia are often attributed to El Nino events, associated with warm sea surface temperature anomalies in the eastern equatorial Pacific and cool anomalies to the north east of Australia. These ocean anomalies are associated with extremes in the Southern Oscillation, a zonal (east/west) circulation across the Pacific Ocean in low latitudes. One of the most severe El Nino related droughts to impact on South Australia was in 1982. However not all El Nino events are associated with drought in the Adelaide region, and some of the most significant local droughts have occurred in neutral or even La Nina years when sea surface temperature anomalies in the Pacific are opposite to those observed in El Nino years (See Box on Significant Droughts). In these situations it is likely that the Indian Ocean sea surface temperature anomalies can be a deciding factor, along with the seasonal position of the sub-tropical ridge. For more information on atmospheric and oceanic patterns associated with El Nino and La Nina events and Indian Ocean sea-surface anomalies the reader is referred to the climate pages of the Bureau of Meteorology website (www.bom.gov.au/climate/enso/)

Across southern South Australia dry winters typically occur when the subtropical ridge is stronger than usual, with the westerly wind belt then favouring more southerly latitudes. Hence the subtropical ridge, and associated blocking highs in the Australian region, play a major role in steering frontal systems further south of South Australia than usual. Changes in the subtropical ridge occur over short time scales, through natural variability, but a broadening and strengthening of the sub-tropical ridge has been observed in recent decades, most strongly in autumn and early winter, and this has been attributed to increasing greenhouse gas emissions with a resultant drying trend seen in rainfall in southern Australia. This effect is further complicated by changes in the frequency of rain bearing cut off lows, which may actually increase under a strengthened sub-tropical ridge, though these systems need good connections with tropical moisture to produce substantial rain.

Autumn and Spring

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

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

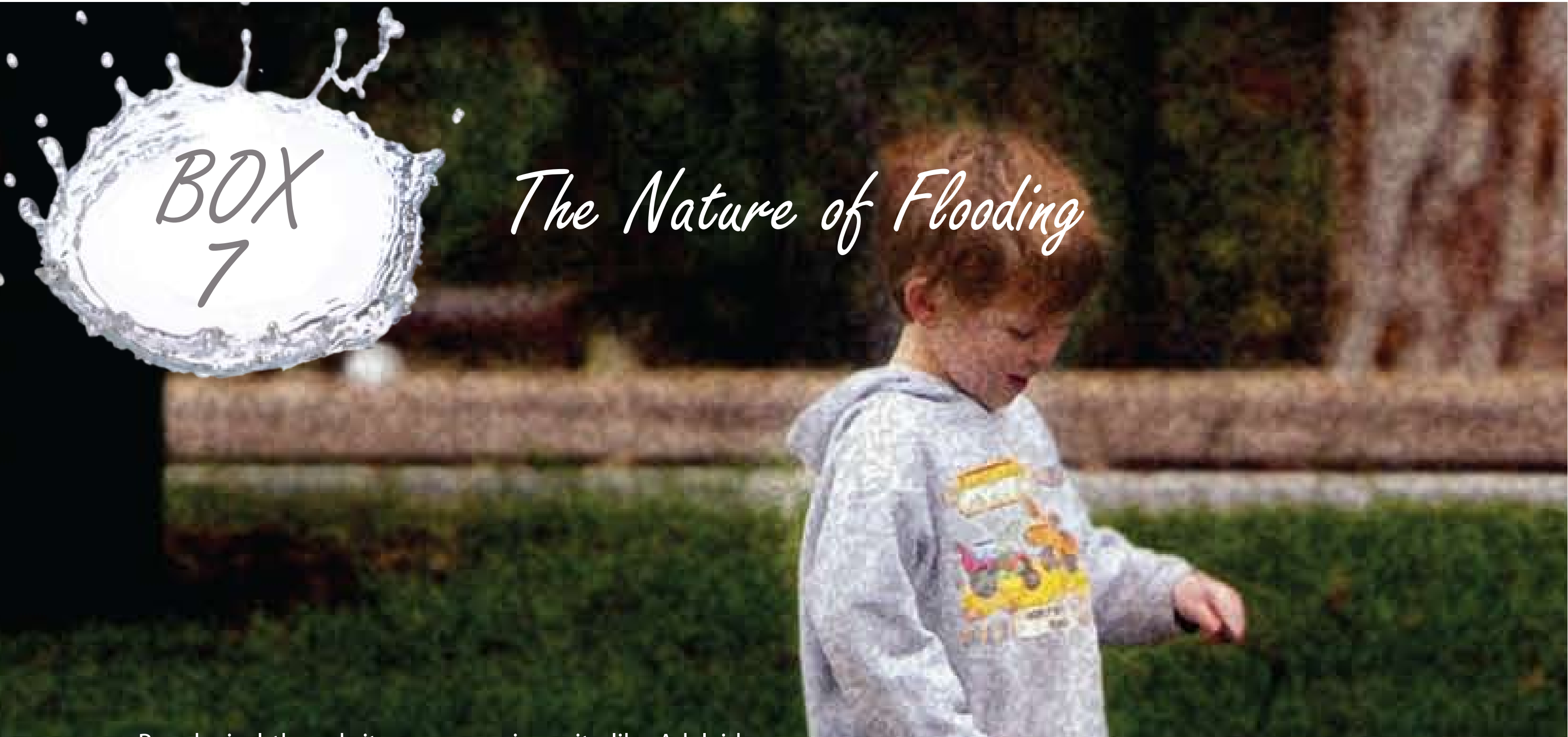
Selected Climate Statistics for Adelaide

Temperature

In the warmer part of the year, November to March, maximum temperatures occasionally exceed 40° Celsius, while in winter overnight minimums can dip to near zero - especially in sheltered areas of the Mount Lofty Ranges. Average maximum temperatures are typically higher and winter minimums colder in drought years when there is less water vapour in the lower atmosphere.

In summer and early autumn mean maximum temperatures

BOX 7 The Nature of Flooding



Paradoxical though it may seem, in a city like Adelaide, which is prone to water shortages, flooding still constitutes a natural hazard for residents, and has done so since the earliest days of settlement. Risks are heightened where inappropriate development has occurred on the floodplain. In many instances it is not a question of if properties will be flooded but when. Planning is of paramount importance in avoiding problems with inundation by floodwaters.

Floods are essentially a consequence of rainfall events and relief, but the costs to society largely result from human activity and economic development. Wise management of flood plains is imperative in reducing the costs of damage by flooding. In many instances humans increase the flood risk, by actions such as channelisation and construction of flood control embankments. Furthermore, urbanisation invariably increases the volume, speed and height of run-off from storm events, thereby exposing properties sited on flood plains to even greater damage from inundation. Flood proofing activities may actually produce an unwarranted sense of security on flood plains of considerable risk.

There are several major different types of flood events that affect the Adelaide area:

1. Flooding from perched river channels

The lower reaches of many streams flowing across the gently sloping alluvial plains diminish in channel capacity, flood out and construct natural levees along the channels. In this fashion the stream becomes perched above the surrounding floodplain so that if the levee is breached or overtopped then dramatic flooding may occur. The Gawler River, Little Para River, Dry Creek and the Torrens River all become perched streams in their lower reaches. Ironically, places close to the river built on the high levees are safer from flooding than lower lying areas sometimes kilometres from the streams. The Gawler River has a catchment area of 1070 km2 with most of its lower 30 km channel between Gawler and the sea being perched above its floodplain. Severe flooding occurred in 1992 when three 1 in 100 year floods occurred. Similar flooding has occurred in the lower Torrens Valley with the 1931 flood especially severe.

2. Localised stormwater flooding

Localised stormwater flooding may occur at any location throughout the year. These types of events invariably lead to ponding and flooding where the drainage system is blocked or is inadequate to deal with the volume of water, which needs to be evacuated. The impacts of localised stormwater flooding have been magnified by the increased amounts of impermeable surfaces such as roadways, paths and houses. A localised flood in the Waterfall Gully area occurred during 7-8th November 2005 following a storm event in the upper catchment area. Not only were guard rails and walking tracks damaged but houses below the falls were flooded and Wilson Bog failed resulting in the formation of a debris avalanche which flowed down the valley and filled the weir at the base of the First Waterfall with some 10,000 tonnes of peat, sand pebbles and boulders. Without the trapping effect of the weir extremely serious damage would have ensued, and even possible loss of life.

3. Coastal flooding
Storm surge effects

Storm surges occur when there is a coincidence of a high astronomical tide (e.g. a spring tide when the earth, sun and moon are aligned and the gravitational pulls of the sun and moon are maximised), low barometric pressure, which causes the level of the sea to rise, and strong, persistent onshore winds pile up water at the shoreline. These weather-generated enhancements of predicted tide levels can lead to direct flooding of low-lying coastal areas such as tidal creeks, and indirectly intensify coastal erosion on sandy beaches. The effectiveness of waves is increased during storm surges as there is less frictional retardation at the wave base and major storm damage can occur.

Port Adelaide suffered storm surge flooding on many occasions. In 1865 many dwellings were flooded with seawater after embankments were breached. 4 m high tides including the storm surge component have a recurrence interval of 100 years, or in other terms, that there is a 1 in a hundred chance of a 4 m tide occurring in any year[1]. ides near the 4 m level occurred in 1960, 1972, June 1981 and July 1981 at Port Adelaide[1]. The Port Adelaide area is known to be subsiding due to compaction of sediments and tectonic dislocation so that the risk from coastal flooding is likely to increase in the future even if the predicted sea level rise associated with global warming does not occur. It is relatively easy to identify areas that are prone to tidal flooding using biogeomorphic units across tide-dominated coastal sedimentary environments. Unfortunately much development has already occurred in flood prone area so that protective embankments may need to be improved in the future.

Combined storm surge and run-off from land

Often the conditions that give rise to storm surges will also cause rainfall that exacerbates the flooding problem as the floodwaters cannot easily escape to the sea because of the elevated tidal levels. The Patawolonga Basin has been affected by such flooding sometimes heightened by management issues related to the operation of the gates and lock system. Concrete channelisation of the lower Sturt River has accelerated the delivery of floodwaters to the basin, thereby increasing the flood risk. Additional lock gates have been installed and floodwaters have also been diverted directly out to sea via the Barcoo Outlet in attempts to overcome the flooding problem. However, increasing the time of rise of floodwaters and reducing the height of the flood peak by retaining more water on the land would also assist. A flood control dam has also been built in Sturt Gorge to smooth out the flow of floodwaters down to the Patawolonga Basin.

Port Noarlunga is sometimes threatened with flooding as a consequence of a combination of high tides, storm surges and flood runoff from the River Onkaparinga. The impacts of flooding have sometimes been exacerbated by management strategies employed, whereby water retention is maximized in reservoirs such as Mount Bold. When reservoirs are near to maximum capacity, storm events upstream result in reservoir managers 'pulling the plug' so that individual flood events are accentuated over and above what would have occurred if the river had been allowed to run freely. In more recent times management of reservoir levels seems to have been more sensitive, utilizing the reservoir as a flood control measure. However, the water shortages of the past few years may once again encourage the maximization of water holding within the reservoirs so that if the reservoir is full and a storm occurs then the response may well be to once again pull the plug, with minimum warning. Mount Bold last overflowed in November 2005 when little warning was given of the potential flood risk.

Robert Bourman

Table 2.1 Temperature Statistics for Adelaide

	Mean Monthly Maximum (˚C)	Extreme Daily Maximum (˚C) Date		Mean Monthly Minimum (˚C)	Extreme Daily Minimum (˚C) Date	
		Lowest	Highest		Lowest	Highest
Summer	26.9 - 29.3	15.4 3 Dec 1955	46.1 12 Jan 1939	15.5 – 17.1	6.8 3 Dec 1955	33.5 24 Jan 1982
Autumn	19.0 – 26.2			10. 2 - 15.1		
Winter	15.3 – 16.6	8.3 29 Jun 1922	29.1 31 Aug1911	7.4 – 8.2	-0.4 8 Jun 1982	18.4 30 Aug1993
Spring	18.9 – 24.8			9.6 – 13.8		

Table 2.1 Temperature Statistics for Adelaide. Mean monthly temperatures are based on records from the Bureau of Meteorology, Kent Town from 1977 to 2007. The range of temperature shows the variation between the mean monthly temperature of the coolest and warmest month in the season. For example in Summer, December is the coolest and February the warmest month, with a mean maximum temperature of 26.90C and 29.30C respectively. Extreme daily temperatures shown in the table have been derived from the combined daily temperature record of Kent Town and West Terrace, commencing in 1887.

are in the high twenties. On average, the warmest month is February, although the highest daily temperature in the full instrumental record (dating back to 1887) is 46.1 °C on the 12 January 1939 (see Table 2.1). Both January and February are warmer than December, with more than 10 % of days in these months having a maximum temperature exceeding 37 °C. Mean minimum, temperatures in summer are in the mid teens, although the monthly averages mask the overall range. The lowest overnight minimum of 6.8 °C occurred in December 1955 (when snow was observed on the Mount Lofty Ranges), and the warmest of 33.5 °C, was in January 1982.

In winter months daily temperatures are in the mid teens, and overnight temperatures average below 10 °C. The coldest month is July with a mean monthly maximum of 15.3 °C and a mean minimum of 7.4 °C. In the city temperatures rarely fall low enough for frost to form (zero degrees at ground level). At Kent Town frost occurrence is much less than one day per month during winter but frosts are more common in exposed low lying areas on the plains and in the Mount Lofty Ranges.

Table 2.1: Temperature Statistics for Adelaide

Rainfall

Adelaide's mean annual rainfall is around 550 mm in the city, but there is a gradual increase across the plains from around 400 mm on Lefevre Peninsula, to over 600 mm in the foothills. This gradient is accentuated on the western slopes of the Mount Lofty Ranges where at higher elevations such as Uraidla and Mount Lofty the mean annual rainfall exceeds 1100 mm, and then decreases sharply, demonstrating a classical orographic rain shadow to the east. Moving north across the city annual rainfall totals decrease from near 630 mm at Happy Valley in the south to around 430 mm at Elizabeth and then 500 mm at Gawler on the lower slopes of the Ranges. Consequently the average rainfall across local river catchments varies markedly. In the Ranges the highest annual rainfall in a calendar year is 1853 mm, recorded at Aldgate in 1917. However in its wettest 12 month period (May 1923 to April 1924) Mount Lofty Summit recorded 2130 mm.

Figure 2.3: Rainfall totals

In any year the increase in rainfall across the plain is evident, but from year-to-year the annual total at any one locality will vary greatly. Records dating back to 1839 show Adelaide's

Rainfall Totals

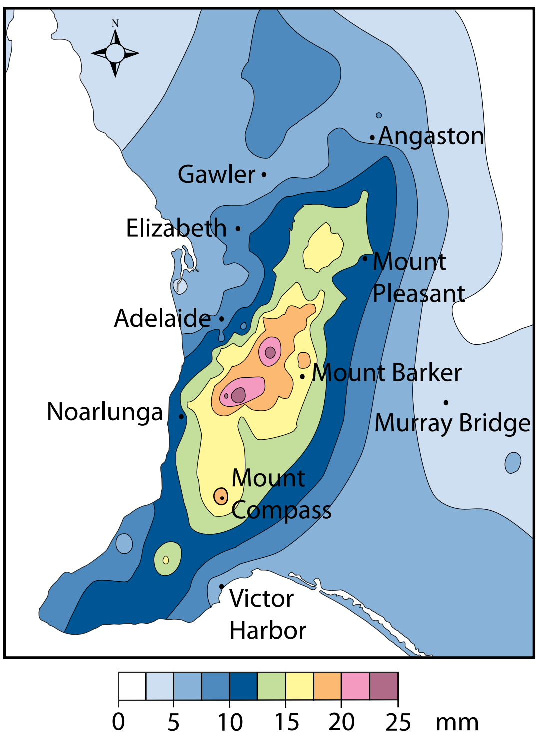


Figure 2.3 Map of rainfall totals in the Adelaide

Figure 2.3 Map of rainfall totals in the Adelaide region for the twenty four hours to 9 am of the 17/07/2007

Table 2.2 Rainfall Statistics for Adelaide

Month (Number of years of data - Kent Town - ***West Tce***)	Median monthly rainfall (mm) ***(West Tce)***	Mean number of raindays ***(West Tce)***	Highest monthly/ yearly total (mm)	Year ***(West Tce, year)***	Lowest monthly/ yearly total (mm)	Year ***(West Tce, year)***
January (30) ***(140)***	21.7 ***(13.3)***	4.6 ***(4.4)***	42.2 ***(84.0***	1996 ***1941)***	0.4 ***(0.0***	1992 ***1957)***
February (31) ***(140)***	10.4 ***(10.2)***	3.4 ***(3.9)***	63.0 ***(154.7***	2003 ***1925)***	0.0 ***(0.0***	2007 ***1965)***
March (31) ***(140)***	20.2 ***(17.0)***	5.5 ***(5.5)***	106.0 ***(116.6***	1983 ***1878)***	0.0 ***(0.0***	1994 ***1870)***
April (31) ***(140)***	32.6 ***(38.3)***	7.9 ***(9.4)***	105.6 ***(154.7***	1998 ***1971)***	0.8 ***(0.0***	1981 ***1945)***
May (31) ***(140)***	56.6 ***(61.5)***	12.0 ***(13.3)***	128.0 ***(196.9***	1987 ***1875)***	8.2 ***(2.6***	2005 ***1934)***
June (31) ***(140)***	82.2 ***(65.0)***	15.0 ***(14.8)***	174.6 ***(217.9***	1981 ***1916)***	12.4 ***(6.0***	2006 ***1958)***
July (31) ***(140)***	68.8 ***(65.0)***	16.4 ***(16.2)***	159.8 ***(138.5***	1986 ***1890)***	22.2 ***(10.1***	1997 ***1899)***
August (31) ***(140)***	69.2 ***(58.6)***	16.0 ***(15.8)***	129.0 ***(157.7***	1992 ***1852)***	11.4 ***(8.4***	2006 ***1944)***
September (31) ***(140)***	58.0 ***(47.4)***	13.4 ***(13.2)***	151.4 ***(148.1***	1992 ***1923)***	16.0 ***(7***	1987 ***1951)***
October (31) ***(140)***	43.0 ***(42.2)***	10.5 ***(10.9)***	105.0 ***(133.2***	1980 ***1949)***	1.0 ***(1.0***	2006 ***1969)***
November (30) ***(140)***	30.8 ***(24.0)***	8.1 ***(7.8)***	107.0 ***(113.2***	1992 ***1839)***	1.0 ***(1.4***	1996 ***1967)***
December (30) ***(140)***	23.8 ***(20.6)***	6.9 ***(6.2)***	72.8 ***(101.1***	1993 ***1861)***	5.8 ***(0.0***	1991 ***1904)***
Annual (29) ***(140)***	560.8 ***(526.2)***	119.7 ***(121.4)***	883.2 ***(786.4***	1992 ***1851)***	287.6 ***(257.8***	2006 ***1967)***

Table 2.2 Rainfall statistics for Adelaide city using records from Kent Town (1977- 2007) and West Terrace (1839 -1978). The median is the mid-point of all observations at the station; ie in 50 % of years the rainfall is greater than the median. Kent Town is around 3 km closer to the Mount Lofty Ranges and so has a higher annual median than West Terrace. The longer record at West Terrace gives a more representative range of extreme rainfalls in the Adelaide region than does the limited 30 year record at Kent Town.

official annual rainfall have varied from a low of 257.8 mm in 1967 to a high of 883.2 mm in 1992. As a guide to rainfall reliability, comparison of annual totals from Kent Town shows approximately one third are below 500mm, one third lie above 600 mm and the remainder lie between 500 mm and 600 mm, with the mid point (or median) at 553 mm.

Between November and March rainfall is unreliable, with February showing the greatest year-to-year variability. In the 168 years of combined record for West Terrace and Kent Town February's monthly rainfall has ranged from zero in several years to a total of 154.7 mm in 1925. Most of this 1925 total was recorded in just one severe thunderstorm lasting several hours (See Box on Significant floods in the Adelaide region).

The transition from dry to wet conditions typically occurs in April/May, when in most years the westerly stream and associated travelling fronts move into Adelaide latitudes. Adelaide's most reliable rainfalls occur under the westerly regime. From May to September the average Kent Town rainfall exceeds 50 mm in each month.

Table 2.2 summarises the rainfall statistics for the city using records from Kent Town and West Terrace. Due to its proximity to the hills, Kent Town has a higher annual median rainfall than West Terrace. However the records show that in the 30 year period, 1978-2007, the median monthly rainfalls and mean number of rain-days in April and May were less than at West Terrace. This is consistent with a belated start to the winter rains in recent years and less prominence of the westerly stream in these months.

This year-to-year variability highlights the importance of using more than just a few years to assess the average rainfall

Wind Roses

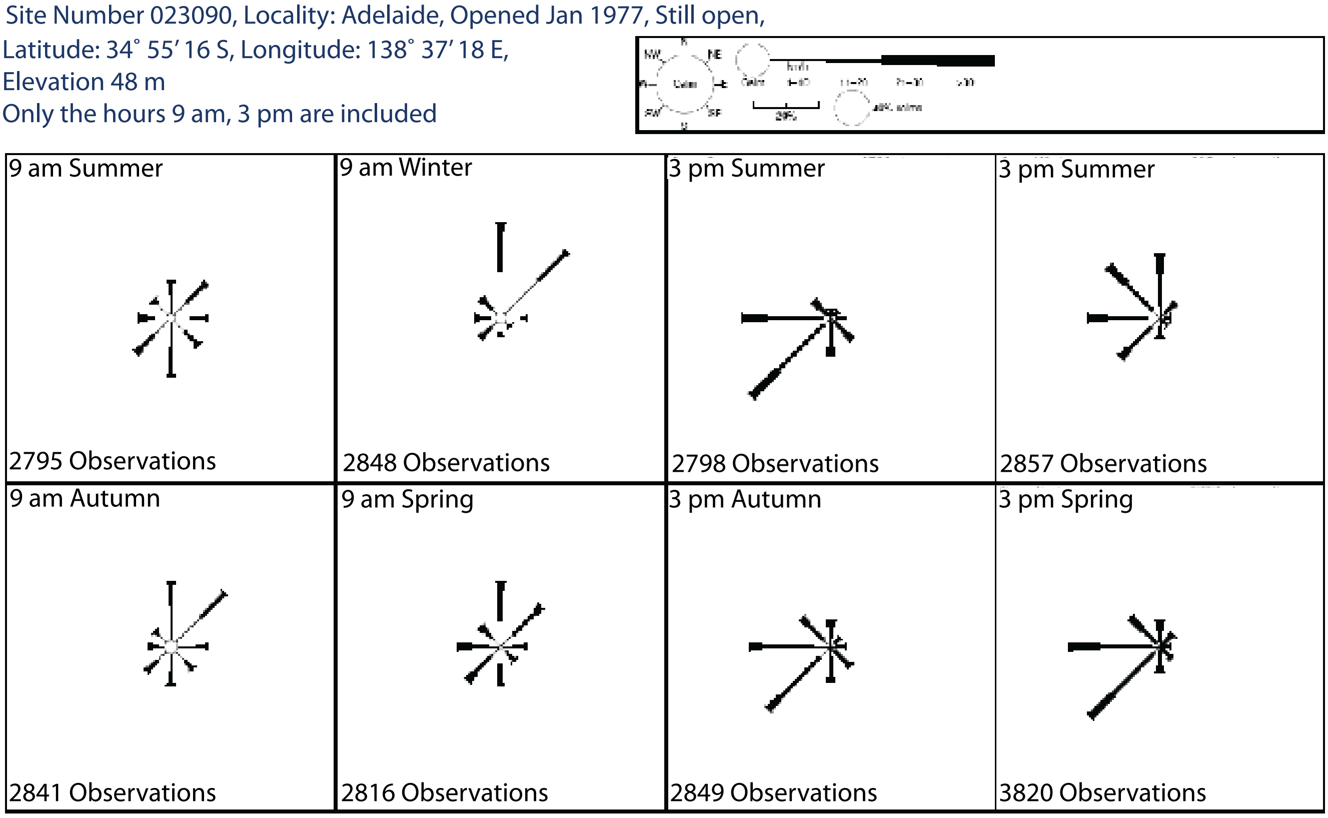


Figure 2.4 Wind roses from Kent Town (Adelaide) showing the prevailing northeast to southwesterly winds in winter, and south to southeasterlies in summer with the afternoon south westerly sea breeze. The data was collected between 1977 and 2008. Source: Office of the Bureau of Meteorology

at any location, and why it is important to use standardised data when comparing climate at different locations or over time. The standard climate period, used by the World Meteorological Organization, is 30 years, with 1961-1990 the current baseline period used for global comparisons. Longer records are required to assess and attribute climate trends.

Table 2.2: Rainfall statistics for Adelaide

Wind

During the day when heating from the sun mixes the lower layers of the atmosphere, the surface wind is generally representative of the prevailing wind pattern. Overnight cooling at ground level usually separates the surface layer from the prevailing air-stream and localised wind regimes become important. In winter prevailing north to south-west winds dominate in an overall westerly air-stream, though overnight a low level north-easterly drift is common over the plains as the westerly stream is blocked by the ranges. During summer southerly winds prevail. The afternoon south-westerly sea-breeze, driven by the heating of the land surface, is superimposed on this stream, often increasing the wind strength, especially along the coast. Overnight gully winds may occur along the foothills. These refreshing breezes result from local cooling after dusk of air in contact with the higher ground and sloping sides of the gullies. As this cooler air is denser than the surrounding 'free' air it rolls down the slopes, and along the gully floors until it spills out on to the plains and its momentum is dispersed. Occasionally these light easterly winds are strengthened and extend much further westwards across the suburbs as they are reinforced by strong and gusty down-slope winds resulting from the surge of a cool southeasterly stream ahead of a new high moving into the Bight. Wind roses for January and July are shown in Figure 2.4.

Figure 2.4: Wind Roses

Water loss to the atmosphere

Water loss to the atmosphere, occurs through evaporation from water surfaces and through transpiration from plants. Various methods are used to estimate such water loss. Here our discussion is confined to ''pan evaporation' and 'evapo-transpiration'. Every day significant amounts of water vapour are lost to the atmosphere through evaporation. It occurs from open water surfaces such as rivers, lakes and reservoirs and through less obvious sources such as bare soil and other wet surfaces. Pan or 'potential evaporation' is a measure per unit area of the amount of evaporation that would occur if an unlimited water source was available. It is measured using a metal pan evaporimeter, gives a good indication of the evaporative loss from a large water source such as a lake or reservoir. Pan evaporation rate is dependent on temperature of the surrounding air and water, solar irradiation or sunshine, relative humidity and wind strength. In fact wind strength is of critical importance, and is the major factor in the differing evaporation rates between a sheltered spot, such as a garden, and an exposed field site or water expanse.

Floods in the Adelaide Region

BOX 8

Floods are natural events, but the relatively low rainfall in Adelaide and the frequent dry periods mean that they do not rank highly against other risks such as bushfires. People who live in Adelaide are often unaware that floods might be a risk to themselves, their animals and their property. Floods are most common in the winter months, July through October, but can occur in any season. In fact the most extreme short duration rainfall rates – capable of causing flash flooding, are most likely to result from severe summer storms feeding off tropical moisture. The most extreme rainfall on record occurred in February 1925 when 150mm of rain fell in 3 hours.

Cut-off lows have the capacity to produce the most devastating flooding of waterways in the Adelaide Hills and across the plains. Divorced from the westerly belt, these slow moving systems can produce rain events lasting 12 -24 hours - far longer than travelling fronts. A mixture of stratiform and convective clouds, including thunderstorms can result in extensive rain interspersed with heavy downpours. The winds associated with the system can be strong and recirculate moist air over Adelaide, giving successive rainfall bursts. When these winds are westerly the rainfall intensities over the Adelaide Hills will be enhanced. The cumulative effect of all these factors can lead to exceptional rainfall and subsequent flooding.

One such event occurred in November 2005. Falls of 100 to 120 mm in 6 hours on already saturated ground led to severe flash flooding of a number of creeks across Adelaide, with the worst being Brownhill Creek and First Creek/Waterfall Gully. Hundreds of homes were affected.

Flooding of the River Torrens was a regular event in the early days of settlement, when bridges and houses were periodically washed away. Even as development progressed, builders of housing and infrastructure rarely realised the risk that floods posed. As a result a number of creeks and watercourses were treated as stormwater drains, not as carriers of floods. In particular many privately owned creeks run through backyards. There are many examples of houses built near and over creeks and have a varying standard of capacity for flood flows. Flood waters can be blocked or diverted and will readily break out from the channel, affecting adjacent buildings and facilities. While the creeks function well under normal flows, the result could be disastrous during major flood events.

Remedies to reduce the potential for floods are limited where residents have built over creeks and/or where the natural flow of the creeks has been ignored. The cost to the Government to buy back high risk properties, and land is greater than the community will pay. In 2007 a trial program commenced to better educate the community. All residents in high risk locations were visited, the flood risk explained and practical approaches were demonstrated to minimise damage when a flood occurs.

As flood hydrology became better understood, planning and development became more flood conscious. During the 1980's the Torrens was recognised as a significant flood risk especially where its banks were narrow and steep, and provided little room for the increased flow of floods. To counter this the Kangaroo Creek Dam was raised to provide more flood storage, while downstream the banks were laid back and much of the introduced vegetation that caused blockages was cleared out. At the same time construction of the O-Bahn along the river assisted in providing an open channel suitable to contain floods. The resulting Linear Park has resulted in a reduction in for the 1-in-100 year flood risk.

Chris Wright

At Kent Town, an open site but somewhat sheltered from extreme winds, mean monthly pan evaporation exceeds mean monthly rainfall in all months except during late autumn and winter. At Adelaide Airport, a more exposed site, mean monthly evaporation exceeds mean monthly rainfall in all months. Pan evaporation rates at these two sites are shown in Table 2.3.

Table 2.3: Daily Evaporation

Figure 2.5 shows how the ravaging effects of drought on water storages, and the landscape is exacerbated by the inverse relationship between potential evaporation and rainfall. Clear skies and lack of rain in a drought year, maximises incoming solar irradiation and reduces relative humidity, thereby enhancing evaporative losses in an already dry environment. In wet years increased cloud cover and higher relative humidity reduce daily evaporation.

Figure 2.5: Evaporation and Rainfall

Pan evaporation measurements are difficult to automate and as a result, evapotranspiration calculated from other meteorological variables, is becoming a popular tool to estimate daily water losses. Evapotranspiration represents the combined water loss through evaporation from the soil (and water surfaces) and transpiration from plants. It is dependent on vegetation type but is readily calculated using temperature, estimated water vapour pressure gradient between the plant and the atmosphere, solar irradiation, and wind strength. Daily values for a standard vegetative cover (such as lucerne or mown grass) can be readily computed and forecast using numerical weather prediction model output. The calculated value is then used to compute water deficits for different crops and ground covers. Daily evapotranspiration measurements are increasingly being used by South Australian irrigators to determine watering schedules.

Snow

Snow is very occasionally observed on elevated parts of the Mount Lofty Ranges. The weather systems responsible are known as cold outbreaks and bring very cold air from high latitudes over the State. The rapidly moving cold stream becomes unstable as it travels over relatively warmer water producing moderately deep convective cloud. Water vapour sublimes directly to ice crystals in these clouds resulting in snowfalls in higher elevations. The snow is short lived on the ground, as temperatures greater than 0ºC cannot sustain it. Winter is the most likely time for snow but it has been observed on the higher parts of the Ranges in autumn (April 1916) and even in early summer (December 1955). The rare sight attracts a crowd of sightseers.

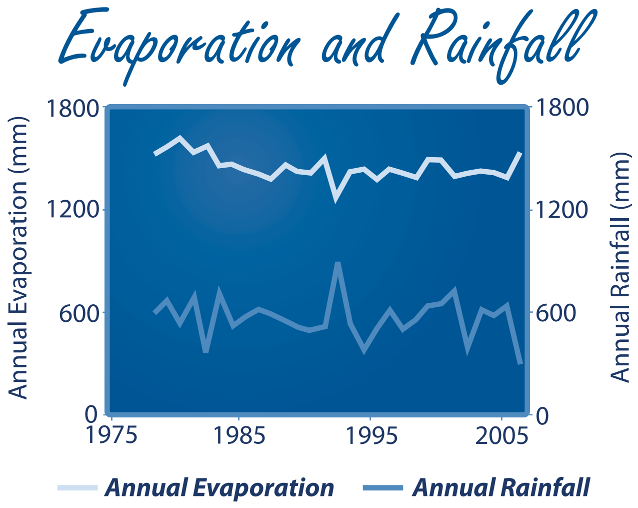


Figure 2.5 A comparison of the annual rainfall and evaporation at Kent Town. In general during wet years such as 1992, evaporation is reduced , while in dry years eg. 1982 and 2006, it is increased. Evaporation is also sensitive to the strength and persistence of the wind run. Variations in wind run from year to year have not been analysed.

Thunderstorms

The Adelaide region typically experiences about 15 days per year when thunder is heard. Most of these storms have life cycles of up to an hour and produce brief heavy downpours. Occasionally more organised severe thunderstorms lasting 1 to 3 hours, may produce flash floods, large hail, tornadoes and/or severe wind gusts. These storms are most likely to occur during late spring and summer, with the majority occurring in the afternoon and evening.

Climate variability, climate trends and climate change

Adelaide's climate has a high natural variability, characteristic of much of Australia, and evident on all manner of timescales; inter-annual, decadal and periods of centuries and longer. Some of the early graphs and tables, based on the instrumental record, give an insight to the considerable month to month and year to year variability in temperature and rainfall patterns. Extreme events such as droughts, flash floods, heatwaves and bushfires, although infrequent, are also natural features of this climate. These events can have a huge impact on the community and economy, and put

Table 2.3 Daily Evaporation (mm/day)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Kent Town	7.1	6.7	4.9	3.1	1.8	1.4	1.5	2.1	3.0	4.3	5.7	6.5	4.0
Adelaide Airport	8.9	8.4	6.5	4.3	2.7	1.9	2.0	2.8	3.9	5.5	7.2	8.2	5.2

Table 2.3 Daily evaporation (mm/day) at Kent Town and Adelaide Airport. The observing sites are approximately 10 km apart. Due to its exposure and greater wind run, evaporation rates are greater at the Airport than at Kent Town in all months.

excessive stress on local infrastructure.

Superimposed on the natural climate variability, there is now clear evidence of recent global warming at rates outside the experience of modern society. In 2007 the Intergovernmental Panel on Climate Change (IPCC, established in1988 by the World Meteorological Organization and the United Nations Environment Programme to provide a scientific assessment of climate change) concluded that globally, a warming trend was 'unequivocal', and most of the observed increase in temperature since the mid-20th century is very likely due to increases in atmospheric concentrations of greenhouse gases attributable to human activities. Paleo-climate information supports the finding that the global warmth observed in the last half century is unusual in at least the previous 1300 years.

In the relatively short historical climate record across southern Australia it is possible to detect recent trends in temperature and various other climate parameters. While the warming is consistent with global trends attributed to human activities the changes in other parameters may be due to external factors such as human activities or they may be part of the natural climate variability or a combination of external and internal factors. For some climate parameters, such as severe storms there is incomplete data to draw global conclusions.

Much research is being undertaken internationally to better understand the observed trends and enable attribution of the cause of these changes. To underpin this research a high quality network of Australian long term climate reporting stations, with records going back to at least the early 20th century, has been identified by the Bureau of Meteorology. The data from this network has been tested to ensure it is free of contamination from effects such as urban heating and poor observational practices. Apart from enabling the detection of climate trends and change, the data are used as input for modelling of future climate and for general climate studies.

An Australian data base of observed trends in selected extreme events and a metadata database for Australia documenting the availability and location of natural systems data holdings are accessible on the Bureau of Meteorology website. These data holdings, mostly held by organisations other than the Bureau, include information on ecosystems and individual species, snow, ice, tree-rings, caves, crops, pollen, sediment, coral, and ice cores.

Recent trends in local climate parameters

Using the high quality climate data sets now available the climate record can be analysed to detect recent trends in our region. Where trends are detected more complex studies are required to determine the cause of the trend, ie whether it is part of the natural cycle or variability, or, whether human activities are responsible. Studies undertaken to determine the cause of a trend are known as 'attribution' studies. Below is a summary of recent major findings based primarily on detection studies:

1. An increase of 0.9 °C is observed in mean temperature for Australia from 1910 to 2006 with most of the warming (0.16 °C per decade) occurring since 1950 (Figure 2.6), With this warming there has been an increase in the number of hot days (> 35 °C) and hot nights (> 20 °C) and a decrease in the number of on cold days (<15 °C) and cold nights (<5 °C) per year.

Figure 2.6: Annual Mean Temperature

2. Annual rainfall in Adelaide shows interannual and multidecadal variability but there is a clear peak during the 1970's (Figure 2.7). On a seasonal basis a recent decline in autumn rainfall is evident across south eastern South Australia including Adelaide. Current research has linked the cause of the decline to changes in mean sea level pressure across southern Australia. The change in the rainfall regime bears some similarities with the more extended and pronounced drying in southwest Western Australia since the 1970's, shown to be due to changes in the large scale winter pressure and wind patterns as well as changes in moisture inflow over the region. Any decline in rainfall translates into a greater percentage reduction in infiltration and stream flow and this amplification increases as the drying conditions are extended in time. This can have serious implications for water storage. The results of extensive research and model simulations of the southwest Western Australian rainfall decline have led researchers to attribute a combination of natural variability, ozone depletion in the stratosphere and increasing greenhouse gas concentrations as the likely cause of this regional change.

Figure 2.7: Annual rainfall

3. Droughts, measured in terms of rainfall deficiencies are peppered throughout the instrumental record (since 1839), but, of significance, the average temperature in

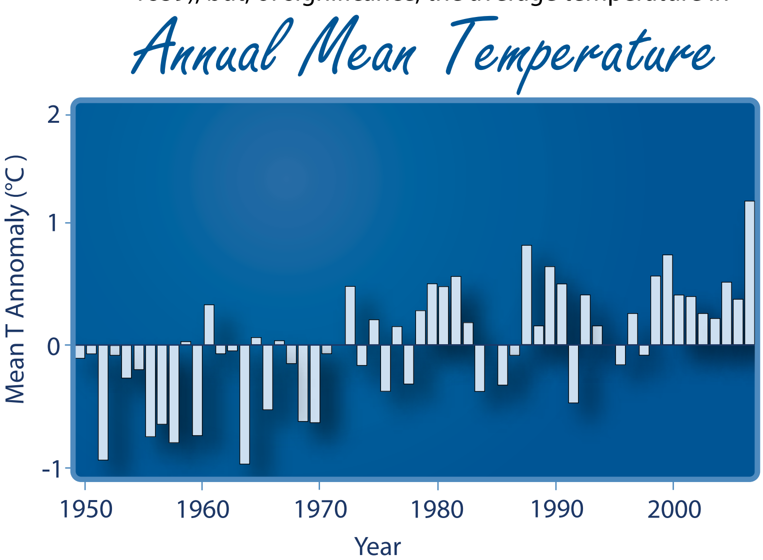


Figure 2.6 Annual mean temperature anomaly for the Adelaide Mount Lofty Region. The temperatureshows a clear warming trend since 1950, and an exceptionally warm year in 2007.
Source: Australian Bureau of Meteorology

recent drought years has been warmer than in droughts of the early 20th century. Warmer temperatures increase heat stress and potential evaporation, impacting on open water storages and soil moisture, reinforcing the severity of the rainfall deficiencies. The timing of rainfall, eg an early 'false autumn break' can also play a critical role in determining water stress for crops.

4. Due to their intermittent nature, changes in the frequency of extreme events, are generally more difficult to assess than changes in mean temperature and rainfall. The likelihood of an individual extreme event is influenced by various climatic factors. This means it is almost impossible to attribute a particular event to a single cause. The occurrence and its intensity is more than likely due to a combination of factors which may include external factors , such as increasing greenhouse gases.

Future Climate Projections

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

Credible climate projections for the 21st century and beyond can only be made using global numerical models which can replicate the current climate features, including the atmospheric and ocean circulations. These models use a range of plausible greenhouse gas emission pathways to produce a suite of future climate projections. Using expert analysis of the output from these model runs, the IPCC,in its 4th Assessment (2007), drew the following conclusions:

1) Most models project global warming over the next two decades to be around 0.2 °C per decade. Continued greenhouse gas emissions at, or above, the current rates would cause further warming and induce many changes in the global climate system during the 21st century that would very likely be larger than those observed over the last 100 years.

2) Sea level pressure is projected to increase in the subtropics and mid-latitudes (Adelaide latitudes) and decrease over high latitudes due to a poleward expansion of the Hadley Circulation and a poleward shift in storm tracks;

3) No consistent discernible change in the El Nino-Southern Oscillation frequency or intensity is evident in the projections;

4) Globally averaged mean atmospheric water vapour, evaporation and precipitation are projected to increase (ie an intensification of the hydrological cycle) but precipitation is expected to decrease in the subtropics and mid-latitudes. Even where mean precipitation decreases, precipitation intensity (mm/unit time) in specific events, such as severe storms is projected to increase, but the duration between such events will also increase.

To enable the impacts of climate change at the regional level to be assessed, a set of climate projections prepared by the international Coupled Model Intercomparison Project is available through the IPCC process. The projections have been developed using 23 different international models which represent state-of-the-art climate modelling. Simulations are available for both the past (20th century) and the future (21st century). Output includes monthly temperature and precipitation data, solar radiation, wind speed and relative humidity. Good representation of the current regional climate gives researchers confidence in the model's skill in simulating the future climate.

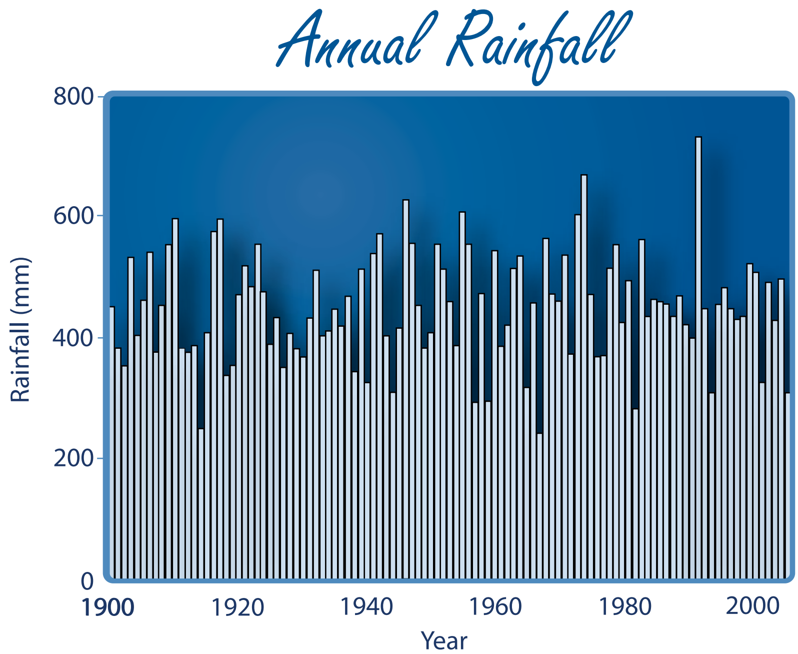


Figure 2.7 Annual rainfall for the Adelaide Mount Lofty Region. The rainfall record shows a high amount of interannual and multidecadal variation. Source: Australian Bureau of Meteorology

A key limitation in developing projections beyond 2030 is that actual future global greenhouse gas emissions are unknown. The emission pathways used in the models are based on those in the IPCC Special Report on Emission Scenarios (2000). Since its publication emissions have been tracking at the high end of the emission scenarios. This infers that unless significant reductions are made to current global emissions trajectories, the most likely future climates are those derived using the higher emission rates in the report. Added to this and little realised by many, is that global warming over the next twenty years or so will largely be driven by past emissions due both to the length of time that greenhouse gases reside in the atmosphere and to the thermal inertia in the ocean- atmosphere systems. This means that adaptation to changes in our climate over the next few decades is inevitable.

Using output from the thirteen models which most closely replicate climate features in the Australian region, the Centre for Australian Weather and

Significant Droughts

BOX 9

Adelaide experiences a highly variable climate. While there have been some devastating droughts of short duration, such as the 10 month El Nino induced drought of 1982-83, the more significant droughts are those associated with dry periods lasting several years. Accumulated rainfall totals fall well below average during these generally widespread events, often extending across most of southeastern Australia.

Extended dry periods which have had a severe impact on Adelaide include:

1864-1869 Very low rainfalls occurred in Adelaide during 1865 and 1869 as part of a more extensive drought in South Australia. In all 6 years Adelaide had very low annual totals, averaging just 434 mm per year, compared with an annual average of 547 mm in the previous 25 years. George Kingston, who had kept meticulous daily records from 1839, assured the colonists, that this short term downturn in rainfall was no more than natural variability. His confidence was justified with the annual total in each of the next 3 years exceeding 565 mm.

1895 -1902 Almost all of Australia was affected by this dry period, culminating in the Federation drought of 1902. 1895-1898 was one of the most severe droughts in South Australia's history, with devastating crop, stock and pasture losses. Adelaide experienced serious rainfall deficiencies (lying in the lowest 10% of records) in1896 and 1897, and below average rainfall in all but one year during the 8 year period.

1914 During the widespread 1911-1916 drought, 1914 saw one of the lowest annual rainfalls on record for Adelaide, and one of the worst years experienced across the State's agricultural areas. Sections of the River Murray were reduced to a series of water holes.

1940- 1950 During this period south-eastern Australia recorded is driest decade in more than 100 years. In six of the seven years Adelaide recorded below average rainfall, with 1940 and 1950 the worst years, but interestingly in no single year did it record serious deficiencies.

1959 - 1967 In this 9 year period there were only 2 years when Adelaide's annual rainfall exceeded the average. The period was a major drought event across inland Australia, and in south-eastern Australia, from 1964. In 1967 Adelaide recorded its lowest annual rainfall, and 1959 was the third lowest recorded at West Terrace.

1982 -1983 This short drought affected all of south-eastern Australia, and is regarded as one of the region's most severe. Adelaide had good autumn rains prior to the event, and good years on either side. The extremely dry weather through winter and spring in 1982 and the summer of 1982-83 turned the surrounding country to a tinder box, culminating in the devastating Ash Wednesday bushfires in February 1983. 26 people lost their lives and nearly 200 homes were destroyed in the State. The total cost of the fires was estimated to be in excess of $350 million.

2006 One of the lowest annual rainfalls on record for Adelaide, with winter and spring rains failing after promising autumn falls. The impact of this one very dry year was exacerbated by an extended seven year period of serious to severe rainfall deficiencies over much of agricultural South Australia as well as the Murray Darling Basin. 2006 saw water restrictions introduced in Adelaide for the first time since 1967. Rainfall improved marginally in 2007 but deficiencies over much of southeastern Australia remained. Adelaide recording below average rainfall in only three years (2002, 2006 and 2007) of the period

Elizabeth Curran

Climate Research (CAWCR) has prepared local regional projections for 2030, 2050 and 2070. The projections give a range of possible values, to allow for differences between each model output. These are the best estimates of future climate, based on our current understanding, and should be used in the knowledge that they will be refined over time.

Based on the CAWCR projections for 2030, the best estimate for annual warming in the Adelaide region, relative to the 1990 is 0.9ºC, with slightly less warming in winter. The number of days with temperatures over 35 ºC is projected to increase from 17 currently to 23 and there is expected to be a small increase (~2%) in annual potential evaporation. The best estimates suggest continued increases in mean temperature and potential evaporation throughout the century.

The projected change in annual rainfall in 2030 is an overall decline of 4%, with the most pronounced declines, of 8% and 6 % in the wetter seasons of spring and winter. The range in the model output projections for annual rainfall spans 'zero change' and varies from -11% to + 2%. The range is determined by ranking all results from the lowest to the highest value - the lowest 10% and the highest 10% (the extreme values) are then excluded. Similarly the projections for seasonal rainfall vary from a decline to a small increase. The uncertainty in sign (an increase or decrease) is most pronounced in summer and autumn. The projections for 2030 also show a small decline (< 1%) in relative humidity and very small increase of +0.2% in solar radiation.

These projections for Adelaide are based on gridded output from the global climate models. They do not take into account local topographical effects due to Adelaide's proximity to the coast and Mount Lofty Ranges, which may have a significant impact on changes, especially in rainfall. A more complete set of projections is available at www.climatechangeinaustralia.gov.au

Care has been taken in writing this text. No responsibility will be accepted by CSIRO of the Bureau of Meteorology or their agents for the accuracy of the projections, or for any person's interpretations, deductions, conclusions or actions relying in the information.

Bibliography

1. Arblaster, J.M. and Meehl, G.A. (2006) Contributions of external forcings to Southern Annular Mode trends. *Journal of Climate* **19**: 2896-2905.
2. Bolle, H.J. (2003) *Mediterranean Climate: Variability and Trends (Regional Climate Studies)* Springer, Germany.
3. BOM (2008) Home Page - Bureau of Meteorology [Online]. Bureau of Meteorology. *www.bom.gov.au*
4. BOM (2003) *The Greenhouse Effect and Climate Change*. [*http://www.bom.gov.au/info/GreenhouseEffectAndClimateChange.pdf*] Bureau of Meteorology.
5. BOM (1998) *Climate of South Australia*. Bureau of Meteorology, Canberra.
6. BOM (1989) *Drought in Australia*. Bureau of Meteorology, Melbourne.
7. CSIRO and BOM (2007) *Climate Change in Australia. Technical Report*. CSIRO and Bureau of Meteorology.
8. Drosdowsky, W. (2005) The latitude of the subtropical ridge over Eastern Australia: The L index revisited. *International Journal of Climatology* **25**: 1291-1299.
9. Dwyer, L.J. (1950) *Results of rainfall observations made in South Australia and the Northern Territory 1839-1950*. Bureau of Meteorology, Melbourne.
10. Evans, A.D. (2007) South Australian Rainfall Variability and Climate Extremes. Thesis, Flinders University South Australia, Adelaide.
11. Grace, W. and Curran, E. (1993) A binormal model of frequency distributions of daily maximum temperature. *Australian Meteorological Magazine* **42** (4): 151-161.
12. Intergovernmental Panel on Climate Change (2007) *Climate Change 2007: The Physical Science Basis. Summary for Policymakers. Contribution of Working Group I to the Fourth Assessment Report of the IPCC*. [*http://www.ipcc.ch/*], Cambridge. Cambridge University Press p. 996.
13. Nicholls, N. (1997) Developments in Climatology in Australia: 1946-1996. *Australian Meteorological Magazine* **46**: 127-135.
14. Physick, W.L. and Bryron-Scott, R.A.D. (1977) Observations of the sea breeze in the vicinity of a gulf. *Weather* **32** (10): 373-381.
15. Sturman, A. and Tapper, N. (2006) *The Weather and Climate of Australia and New Zealand*. (2nd Edn). Oxford University Press, Melbourne.
16. Suppiah, R., Preston, B., Whetton, P.H., McInnes, K.L., Jones, R.N., Macadam, I., Bathols, J. and Kirono, D. (2006) *Climate Change Under Enhanced Greenhouse Conditions in South Australia. An updated report on: Assessment of Climate Change, Impacts and Risk Management Strategies Relevant to South Australia*. CSIRO Marine and Atmospheric Research, Canberra.
17. Szkup, R.J. and Brooks, B.H. (2006) Heatwave trends in Adelaide. *Bulletin of the Australian Meteorological and Oceanographic Society* **19**: 73.
18. Timbal, B. and Murphy, B. (2007) Observed climate change in the southeast of Australia and its relation to large scale modes of variability. *Bureau of Meteorology Research Centre; Research Letter* **6**: 6-11.