Chapter Four
HEATWAVES AND LIFELINES

The impacts of heatwaves extend beyond human suffering. According to *The Sydney Morning Herald*, suspension of work, especially in mines and factories in the late 19th and early 20th century, was common during heatwaves in both Sydney and other New South Wales towns. Some factories reported internal temperatures in excess of 50°C and in Sydney, 500 waterside workers 'walked off' in January 1960 and again in February 1973 when hull temperatures reached up to 44°C.

Deleterious impacts on crops and animals were also noted in *The Sydney Morning Herald*. Agricultural crops were decimated on many occasions, with particularly serious impacts reported if a hot spell occurred in conjunction with strong winds. An estimated 180,000 to 250,000 pounds worth of stock and crops was lost in Queensland alone as a result of a 1940 heatwave, while at Coonabarabran in 1896, 250 sheep out of a 7,000 head flock perished from heat apoplexy (SMH 21/1/1896: 5f). At the Adelaide Zoological Gardens in 1897, a heatwave resulted in the death of a rare and costly drill monkey, a pair of valuable seals and numerous birds (SMH 31/12/1897:5c). Incidents of coach and mail horses dying because of the heat were common. Consequences of heatwaves reported in *The Sydney Morning Herald* are listed in *Appendix 4*.

The impacts of heatwaves are not, however, entirely negative, with increased sales of cold drinks, ice cream and beer reported in Sydney in *The Sydney Morning Herald*, even to the point of a 1949 "Beer Scare" owing to excessive demand and low supply. Zeisel (1950, in Maunder, 1989) reported that beer consumption in Rhode Island increased 2.2% from expected for every 1°C above the average temperature. In Japan, a similar increase of 8% was reported by a leading brewery, which developed a 'brewery's beer weather index', able to predict beer consumption based on the temperatures in 15 areas in Japan (Gabe, 1985 in Maunder, 1989). Retail trade sales in America are generally above average in spring and early summer if conditions are warmer than average (Maunder, 1973).

It is beyond the scope of this thesis to examine all these wide-ranging effects. This chapter focuses on the consequences of heatwaves on lifelines, in particular, transport, water and electricity, in order to indicate the significance of heatwaves on essential infrastructure.

The availability of data means this chapter is concerned primarily with lifelines in Sydney, although reference is made to known impacts in other areas.

4.1. Transport Links

4.1.1 Trains

Misalignments or buckled lines involve the sudden lateral movement of track and occur when heating exacerbates inadequacies in construction of the train track. The most significant factors affecting the temperature at which buckling will occur are the resistance of the track laterally, the degree of lateral restraint, the track curve radius and the initial track geometry imperfection (Tew, 1989).

According to a 1988 State Rail report, most buckles occur before mid-summer due to the effect of high temperatures for the first time on sections of the track which have experienced creep or curve pull-in during winter, or have been subject to track maintenance (State Rail, 1988). Buckled lines and delayment of trains were reported in *The Sydney Morning Herald* as a result of heatwaves on several occasions and at many locations. However, contrary to the findings of State Rail (1988), these occurrences were distributed throughout the summer months. Track buckles resulted in delays of up to 3 hours, and at times water was poured onto the track in an attempt to reverse buckling and end train delays (SMH 27/1/1960:1). Buckled lines resulted in derailments on at least one occasion (SMH 31/10/1958:1). The primary cost of a rail derailment is estimated at US $180,000 but the actual amount may be as much as four times this. A derailment in 1985 cost an estimated two million dollars in lost freight, infrastructure and repair (*pers. comm.* State Rail, 1993). Misalignments alone result in substantial fiscal losses in lost revenue and freight.

The number of misalignments and derailments in New South Wales from 1979/80 to 1988/89 are shown in *Figure 4.1*, and display a declining frequency since 1979/80, reportedly because of improved track standards (*pers. comm.* State Rail, 1994). These

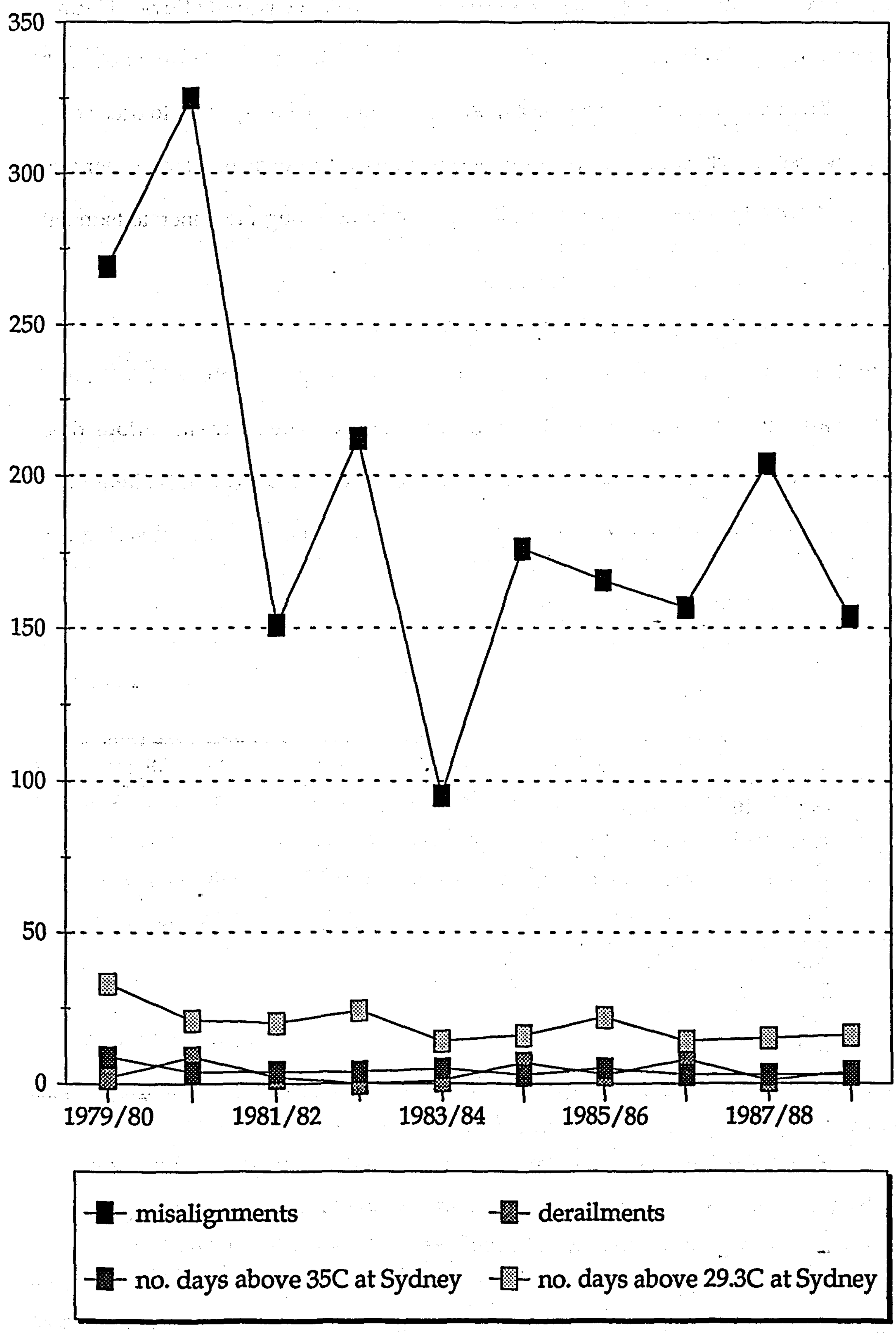

Figure 4.1 The number of misalignments and derailments in New South Wales, 1979-1989, and the number of heatwave days, according to *Definition 2* (maximum temperature ≥ 35°C) and *Defintion 3* (maximum temperture ≥ 29.3°C), in Sydney.

figures were poorly correlated with the number of days above 35°C or 29.3°C in Sydney (*Definitions 1* and *2* from *Chapter 2*), as shown in *Figure 4.1.*

At Toowoomba, the number of rail buckles increased following the introduction of mechanised track maintenance in 1981 because of an associated decline in the standard of the track (State Rail, 1994). However, since the partial introduction in 1986 of the Track Buckling Prevention System (TBPS) which implemented technical improvements and better work practices, there has been a substantial drop in the number of buckles. This exemplifies the impact that human actions can have in increasing or decreasing the effects of natural hazards.

4.1.2 Roads

High temperatures can cause the melting of road materials and asphalt rutting develops as a result of both material melting and traffic loading (*pers. comm.* P.Walter, RTA Technologies Developing Team, 1993). Melting of road materials was reported with heatwaves in Sydney, even to the point of bizarre twists where bitumen on the runway at Kingsford Smith Airport was hosed in order to prevent passengers burning their feet (SMH 27/1/1960:1).

4.1.3 Bridges

The Gladesville Bridge jammed open in November 1957, and January 1960, when high temperatures caused bridge expansion during a standard bridge opening. In January 1960 both the Gladesville and Pyrmont Bridges were hosed by workers to prevent buckling and expansion (SMH 30/1/1961).

4.2 Water Consumption

Reports in *The Sydney Morning Herald* encourage the conclusion that heatwaves have had significant impacts on water consumption. Record rates were registered in conjunction with heatwaves in Sydney, Canberra and Perth, and large increases noted at other locations. During the heatwave of January 1939, record temperatures created water shortages in Canberra and western New South Wales towns due to record consumption rates, leaving many towns with no water for domestic use; for example, water was carried to Ivanhoe from Menindee, a distance of 200km, at a cost of 1/6d for 100 gallons.

Consumption of water in Canberra was almost twice pre-heatwave rates and rationing was considered, although not ultimately necessary.

Water restrictions did occur in some areas of Sydney in 1948 and 1958 and 1960 because of heatwaves. In the period January 27 to February 1, 1960 exceptionally high consumption during a record heatwave[1] resulted in supply difficulties particularly in the northern areas (Sydney Water Board, 1968). The use of fixed hoses and sprinklers was banned at private residences in Hunters Hill Municipality, Manly Municipality and Warringah Shire on the 27th January and for the whole Water Board area on 28th January. Restrictions were lifted following cooler weather and some rain. Failure of the water supply in Sydney was also reported on several occasions in the 1950s and early 1960s, as record demands were placed on the system during heatwaves. The amplification of the supply system since this time has removed this problem (*pers comm.* Ron Atherton).

In order to investigate the plausibility and significance of the hypothesis that a positive relationship exists between water consumption and temperature extremes, total water consumption (in megalitres per day; ML/day) was obtained from the Water Board (Sydney Office). These data are available on a daily basis in computerised format for the period, 1/1/1977 to 6/30/1993[2]. Prior to this period, data were available in hard-copy format in registers, on a monthly basis from 1950 and on a daily basis since 1970.

These early data were used to corroborate reports in *The Sydney Morning Herald* of increased water consumption at Sydney in conjunction with heatwaves. Analysis of these data is included in *Table 4.1*, and with the exception of November 1953, the claims in *The Sydney Morning Herald* are substantiated. *Figure 4.2* shows water consumption and maximum daily temperature for the month of January, 1973 where a record consumption rate was reported on the 22nd. The relationship between temperature and consumption is obvious around the 22nd, but more tenuous for the beginning of the month. The increases reported in *Table 4.1*, however, may be little more than circumstantial,

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[1] Maximum temperatures recorded at Observatory Hill from January 24 to 28 were 31.6°C, 39.4°C, 41.4°C, 42.4°C, 39.7°C.

[2] The consumption for a day actually represents the consumption for the 24 hours prior to 8am on that day. Correlation with the temperature on the proceeding day is therefore necessary, to ensure that the consumption is related to the maximum temperature that occurred during the time period it actually refers to.

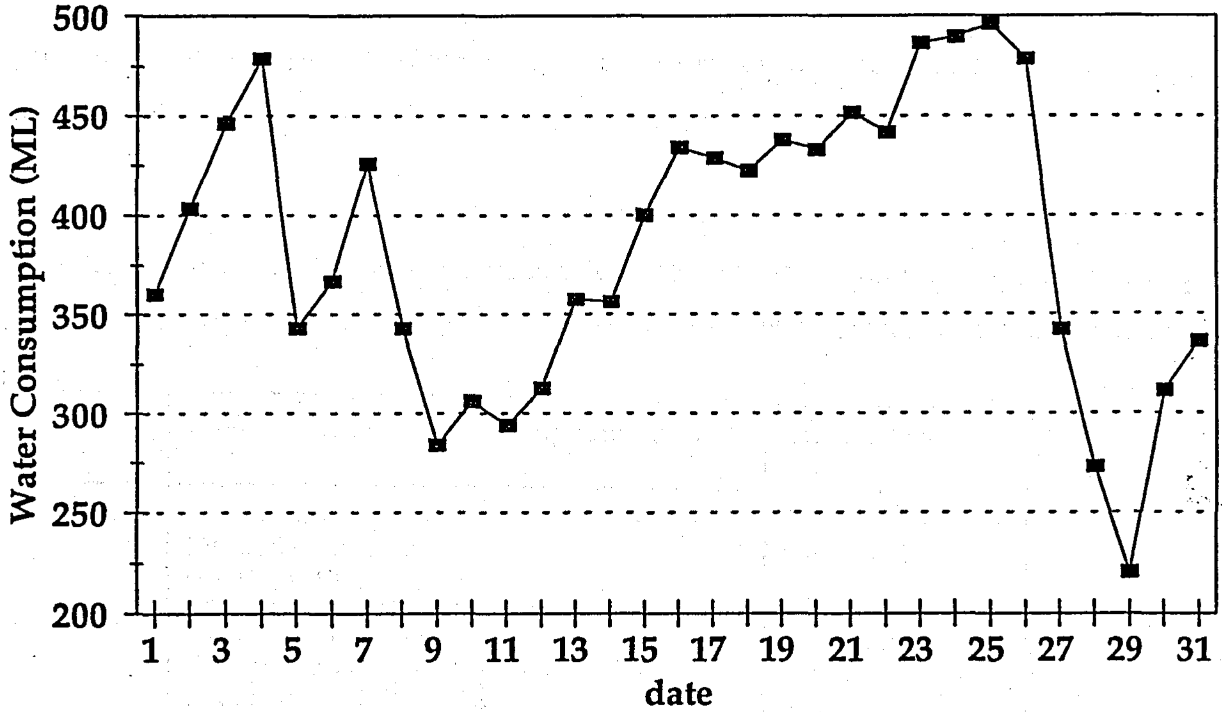

Figure 4.2a Daily water consumption (ML/day) in Sydney for the month of January 1973.

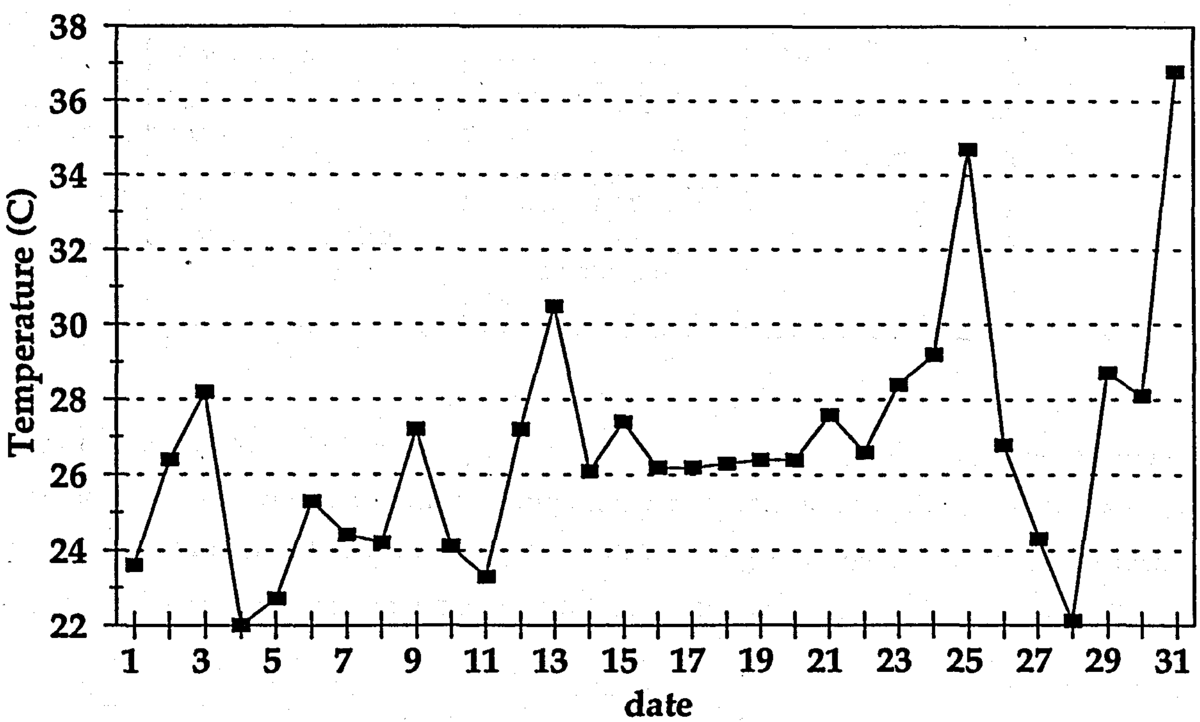

Figure 4.2b Daily maximum temperature (°C) in Sydney for the month of January 1973.

representing the indulgent reaction of the media to the newsworthiness of high temperatures.

Table 4.1: Periods of high water consumption rates recorded from *The Sydney Morning Herald*, supporting data from Water Board Records, and relevant temperature information.

Date	**Comment/Reference**	**Supporting data**	**Temperature**
27/10/1948	record consumption of 230 million gallons (SMH 28/10/1948:3)	no data available	35.2°C, preceding day 36.2°C
18/11/1953	consumption for last 7 days was highest ever (SMH 18/11/1953:1)	no evidence to support claim	temperature ≥ 35°C 3 times in week
4/1/1955	very high consumption (SMH 4/1/1955:1,4)	6% greater than Dec 15% greater than February	preceding day 40.1°C
14/4/1957	record April consumption (SMH 14/4/1957:29)	20% greater than consumption in April, 1958	temperature >30°C on one occasion in month
11/10/1957	very high consumption (SMH 11/10/1957:1)	10% greater than consumption in October, 1958	preceding day 30.9°C
22/1/1973	100 million gallons above normal consumption used (SMH 22/1/1973:3)	30% greater than consumption in January, 1972; and 27% greater than consumption in January, 1974.	see *Figure 4.2*

To assess further the relationship between water consumption and temperature, daily consumption were correlated with maximum daily temperature in Sydney for the period 1980-1993[3]. Although data are available from 1977, changes in the boundary of the area serviced by the Water Board in 1980[4], in addition to the occurrence of water restrictions

[3] Correlations of this kind have never been performed by the Water Board.

[4] The boundary expanded in 1980 to the Blue Mountains, as well as the Sydney and Illawarra Region.

in the northern suburbs in late 1979[5] means that the inclusion of these years would create spurious results.

A scatter diagram between water consumption and maximum daily temperature shows a strong correlation (*Figure 4.3*) (4700 data points). The correlation coefficient of the relationship between water consumption rates and maximum daily temperature is r = 0.55473, which represents a very significant correlation.

Figure 4.4 illustrates the relationship between average daily water consumption and maximum temperature, and elucidates the strong relationship between temperature and consumption. Consumption steadily increases with temperature.

In *Figure 4.5* the variation in consumption by month is shown to display a strong summer peak, with a difference of around 400 ML/day between the maximum December consumption and the June/July minimum. Because of this variation, the deviation of the actual daily water consumption from the expected monthly water consumption based on the 1980-1993 average for the relevant month was calculated in order to standardise for seasonal variations in consumption. In this manner, *Figure 4.6* represents more accurately the degree to which high temperatures result in increases to expected demand. This figure suggests that consumption increases by about 200ML for each 5° temperature increase above 25°C. At temperatures greater than 40°C an increase of over 700ML/day from the monthly average can be expected. This equates to an increase in excess of 40% from the average monthly consumption if the hot day was to occur in the summer months, as would be expected. Considering that consumption is at its annual premium in these months, this represents a significantly high demand placed on the system at a time of, on average, peak consumption.

Annual water consumption in Sydney is highly correlated with the number of rainy days (*pers. comm.* R.Atherton, Water Board). A correlation between the number of days with temperatures above 35°C yielded a very low correlation coefficient (r=0.085). However, a correlation with the annual number of days with daily maximum temperature above 29.3°C illustrated a stronger, but not highly significant relationship (correlation coefficient= 0.45, significant at the 10% level). These results suggest that while

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[5] During a bushfire emergency in late 1979 (Crabb, 1986:19),

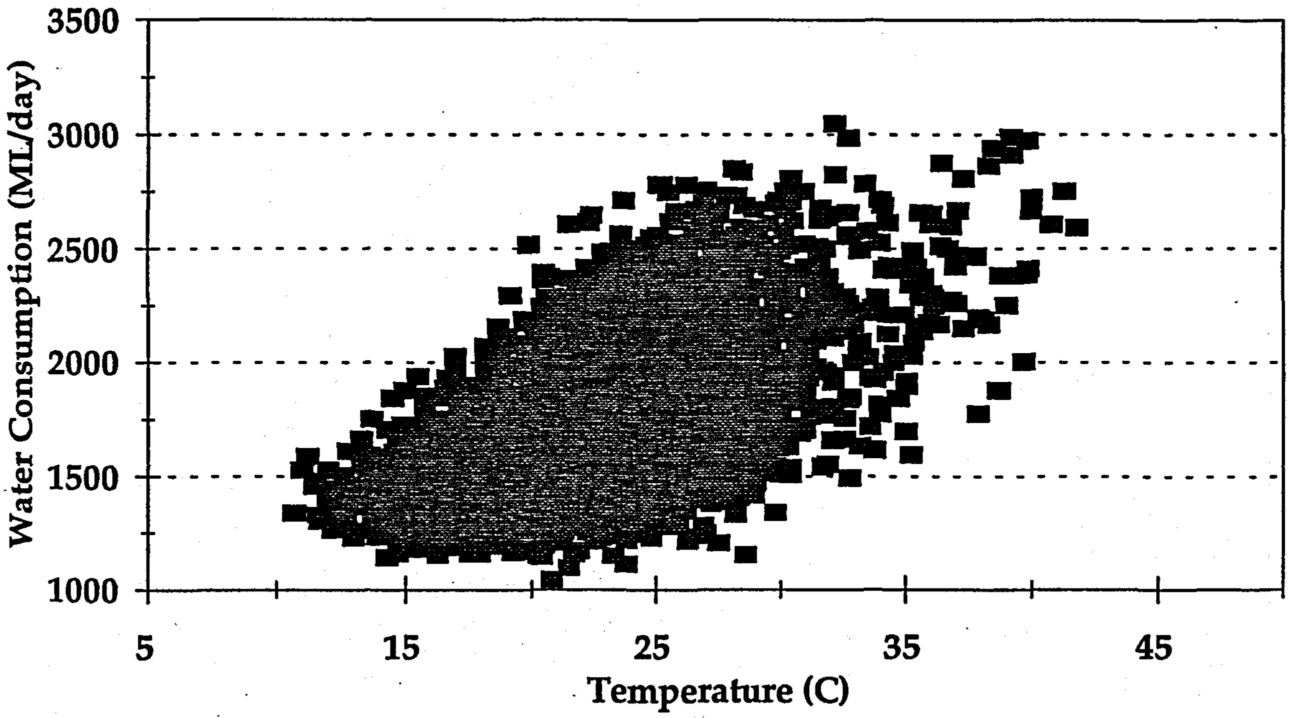


Figure 4.3 Scatter diagram of water consumption and daily maximum temperature in Sydney.

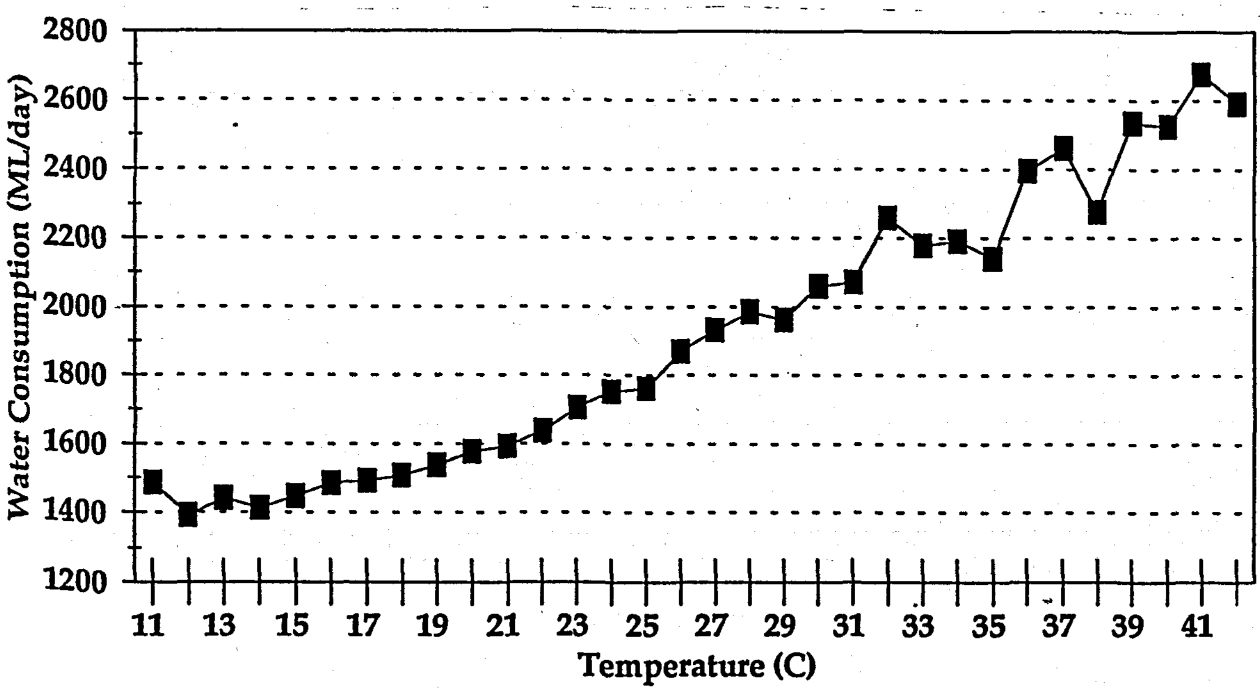


Figure 4.4 Average daily water consumption in Sydney (ML/day) by daily maximum temperature (°C).

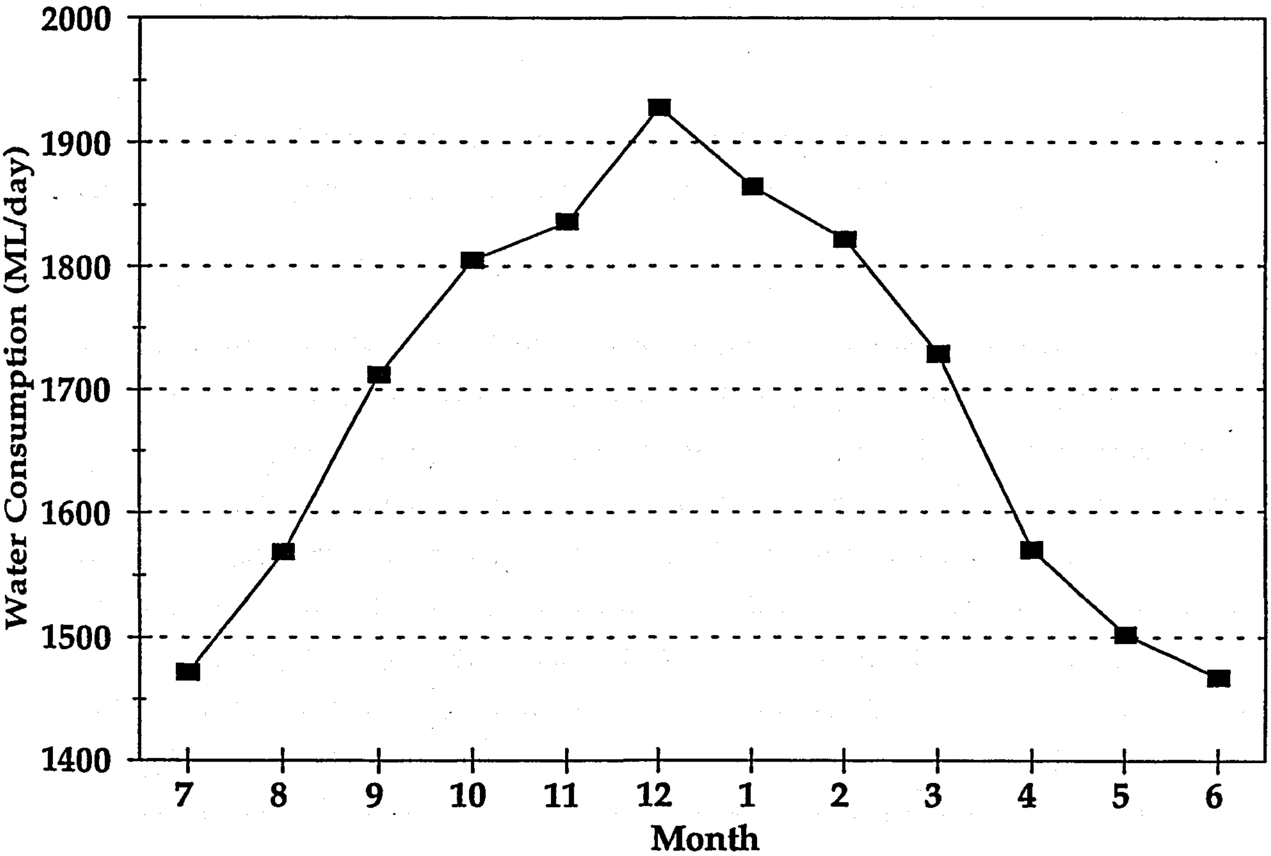


Figure 4.5 Average daily water consumption in Sydney by month.

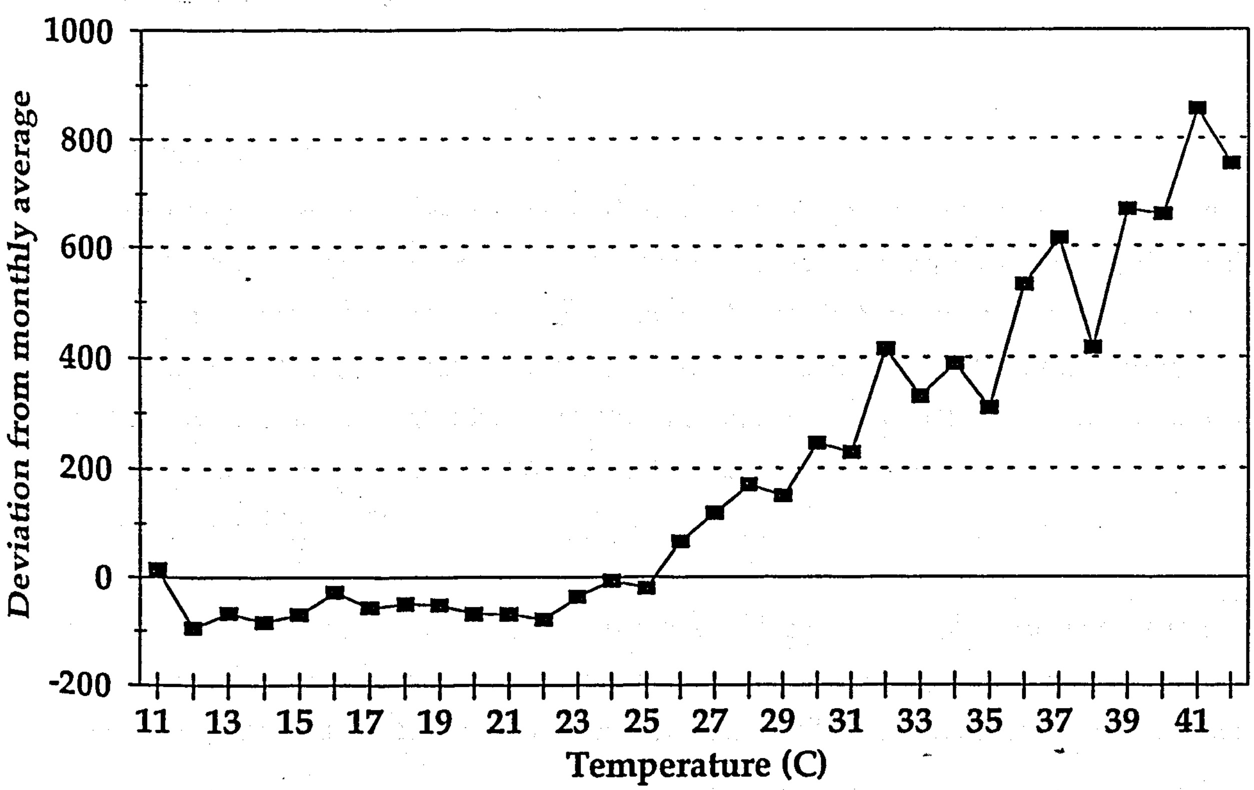


Figure 4.6 The deviation of daily consumption from the expected consumption based on monthly average by temperature (°C).

consumption is influenced on a daily basis by the maximum temperature, the relative 'hotness' of the year is not so significant in influencing the average annual water consumption.

In summary, hot days have the ability to increase the demand placed on the water supply system. In earlier years (pre-1960) this resulted in supply failure and, at times, water restrictions. Improvements to the water supply system have largely eliminated these problems. Still, the large increases in demand on days of high temperatures are potentially significant especially if storage is depleted during drought periods. If water restrictions are imposed (as will occur in November 1994 as a result of widespread prolonged drought), these findings imply that on hot days the increased demand of the population is being denied. Most of this demand, however is probably spent on garden watering (Crabb, 1986). *Figure 4.4* implies reasonable prediction of daily water consumption which, in times of water shortage, could potentially be utilised in conjunction with daily temperature forecasts to increase media education campaigns (on news broadcasts for example) on and preceding hot days, with the aim of minimising excessive consumption. The implications of the findings of this analysis is an area which warrants further investigation.

4.3 Electricity

The association between heatwaves and increased electricity consumption has been illustrated in the United States. Record electricity usage was reported during the 1980 United States heatwave, incurring an estimated one billion dollar national cost in additional electricity (Le Comte & Warren, 1981; Maunder, 1989). The 1963 heatwave in Los Angeles was accompanied by an all-time maximum in electricity use, and similar use maxima occurred in New York, St Louis and other large cities during the 1966 heatwave (Oeschli & Buechley, 1970).

In New South Wales, peak demand was not positively correlated with mean summer daily temperature until the mid 1970s. Since 1976, the relationship between peak summer demand and mean daily temperature has been statistically significant, with the exception of the years 1977 and 1986[6] (Pacific Power, 1992). This trend has been primarily a result of the widespread increase in air conditioning, especially in large office blocks (*pers comm.* P.Gannon, Pacific Power, 1994), and complies with similar patterns in the United States since 1960 (Johnson *et al.*, 1969; Quayle & Diaz, 1980; Karl & Quayle, 1981).

Daily summer peaks of electricity demands now occur between 10am and 4pm, with a tendency to occur between 12pm and 2pm, as opposed to the evening peaks that were standard until the mid 1970s (Pacific Power, 1992).

On a daily basis, demand is positively correlated with temperature when the mean temperature exceeds 22°C. Above this temperature, daily demand increases as temperatures increase, as shown in *Figure 4.7*. *Figure 4.7* also demonstrates that demand is higher at cold temperatures than at hot, although this pattern is changing. As shown in *Figure 4.8* there has been a significant difference in the growth rates of summer and winter electricity peak demands since 1981. This is occurring because of the increasing summer demand for air conditioning, in conjunction with a declining winter demand as natural gas occupies more of the winter heating market. With trends increasing in the present manner, winter and summer peaks are likely to be even some time between the years 2001 and 2010, depending on varying economic scenarios. These predictions have been produced by a forecasting model, developed by Pacific Power, which aims to reflect the exogenous drivers of demand such as population, economic activity, and relative fuel prices, but unfortunately 'de-weathers'[7] trends and assumes no climate change.

The importance of considering temperature anomalies in conjunction with economic growth was noted by Le Comte & Warren (1981), who showed that during the 1980 heatwave in the United States the electricity production index increased by 4%, even though a slow down in industrial activity occurred. The demand that was experienced was actually greater than the increase expected had the economy simply stagnated. With a suddenly rebounding economy, the increased demand would have been even more significant. A similar situation occurred in Sydney in 1991, when the impact of an

[6] the reason these two years differ is not known

[7] Peak demand is de-weathered by "correcting maximum demands for temperature in order to derive a standardised annual maximum demand that would have occurred in any year under similar weather conditions" (Pacific Power, 1992:4)

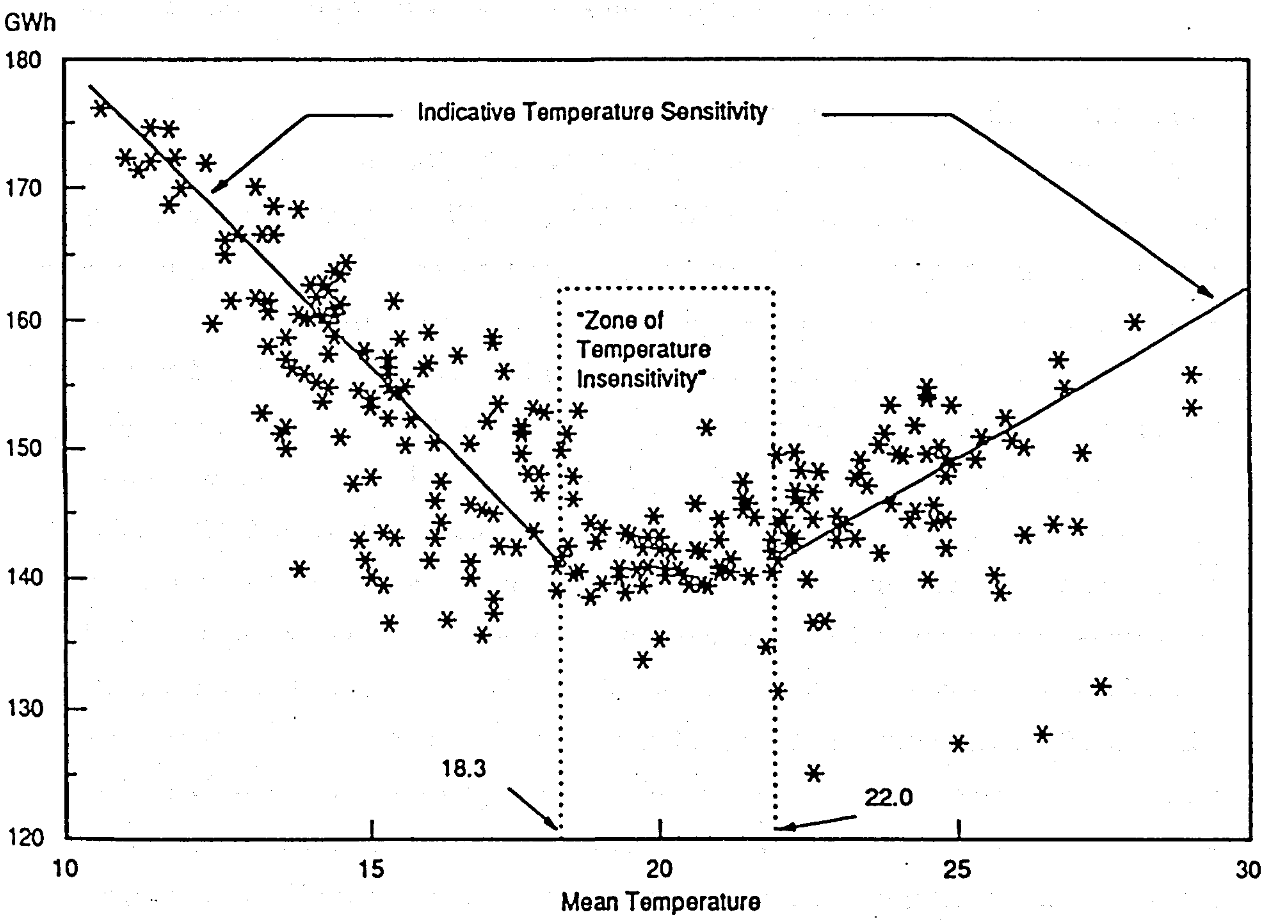


Figure 4.7 Weekday daily energy versus mean temperature, September 1990 to August 1992 (source: Gannon, 1992).

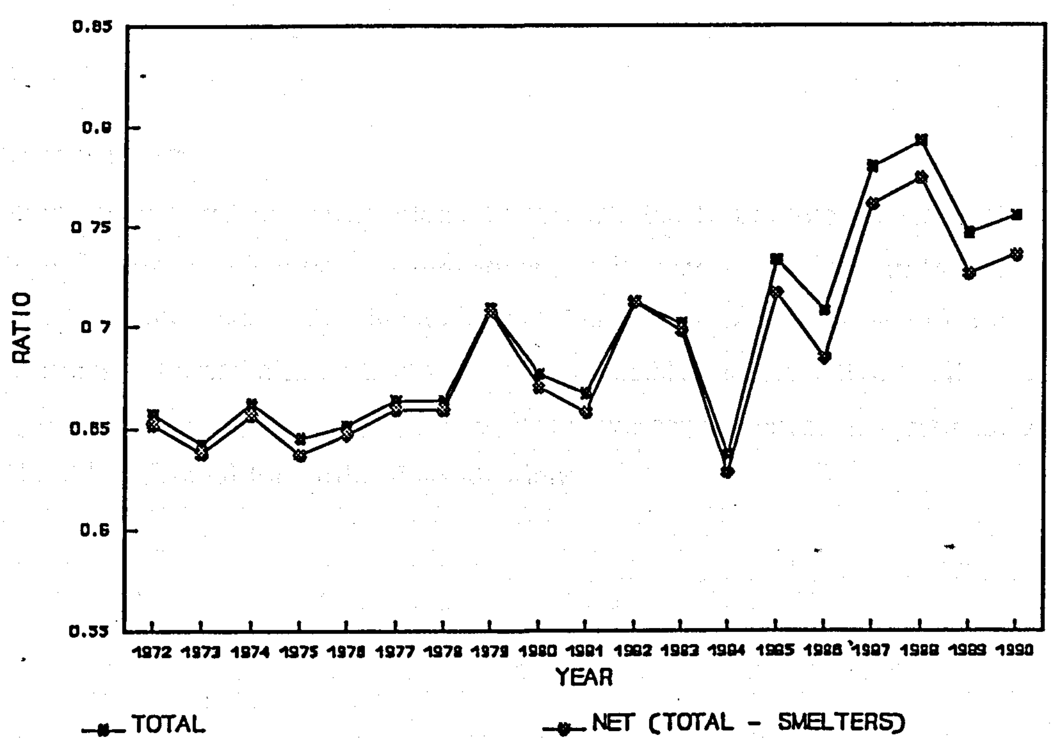


Figure 4.8 Ratio of Annual Summer Electricity demand Peak to Winter Peak (source: Pacific Power, 1992).

economic downturn on electricity sales was offset by unusually warm weather.

Heatwaves have the potential to cause an unusually high peak summer demand, and this makes it important to quantify the relationship between temperature anomalies and energy demand (Le Comte & Warren, 1981). While the de-weatherisation of demand trends is reasonable in terms of predicting normalised consumption it does ignore anomalous situations. In the case of a severe heatwave occurring on a week day in Sydney, it is hypothesised that several problems regarding electricity demand and supply might develop into a disastrous situation. A high peak demand, due to office air conditioning would occur. Due to technical problems based on the heating of power lines, electricity conduction becomes less efficient at high temperatures (*pers comm.* P. Gannon, Pacific Power, 1994). Therefore, at this point of high demand the supply of electricity is impeded. Because forecasting has not allowed for sudden and anomalous peak demands based on extremes of temperature, the supply system may be inadequate to meet this demand. We now reach the point in this scenario where there is the potential for wide spread electricity failure or 'brown outs', at a time when the use of air conditioning is most desired in terms of human comfort. This actually occurred during a heatwave in New York in 1970, when overloaded power supplies eventually failed, blacking out much of the eastern seaboard of the United States (Ellis, 1972). This scenario could result in the exposure of an unacclimatised population to very hot temperatures in unventilated environments, with the potential to provoke a disaster situation, with a high excess mortality rate (Budd, 1990).

4.4 Conclusions

Transport, Water and Electricity lifelines were selected to provide a taste of the range of effects and widespread impacts of heatwaves. It is clear, particularly in the case of water consumption and electricity demand, that heatwaves can have significant economic ramifications. Nonetheless, paucity of data available indicates that lifeline authorities have put little effort into the analysis of heatwave consequences in Australia, indicating considerable potential for further investigations.

Chapter Five
A LINK BETWEEN HEATWAVES AND THE EL NIÑO-SOUTHERN OSCILLATION?

5.1 El Niño-Southern Oscillation

El Niño refers to the anomalous warming of the normally cool equatorial eastern Pacific Ocean off Peru, an occurrence that is linked with the *Southern Oscillation* (SO), an out-of-phase relationship between atmospheric pressure over the South East Pacific and the Indian Ocean. The El Niño/Southern Oscillation (ENSO) phenomenon has serious ramifications for the world's climate, and particularly affects northern and eastern Australia (Nicholls, 1988a). Much of the variation in Australian rainfall is related to ENSO (Coughlan, 1979; McBride & Nicholls, 1983; Nicholls, 1985; Nicholls, 1988b), and a correlation between droughts and ENSO has been confirmed, with most droughts associated with ENSO events and vice versa (Nicholls, 1988a). Other natural hazards are also linked to ENSO. The frequency of tropical cyclones decreases during an ENSO event (Nicholls, 1985) and preliminary analysis of bushfire fatalities suggests that years of high numbers of casualties are positively correlated with ENSO years (Blong, 1991). Outbreaks of the potentially fatal Murray-Valley Encephalitis, the number of green turtles breeding, and sorghum yields also appear to be linked with ENSO (Nicholls, 1986; 1988a). Because of the lifecycle of ENSO, approximately 18 months (Nicholls, 1987), these linkages offer hope for the prediction of drought, northern Australia cyclonic activity, sorghum yields and other related phenomena (Nicholls, 1983; 1985; 1986; 1987; 1988b).

5.2 A Link between ENSO and Heatwaves?

This chapter hypothesises that the occurrence of heatwaves may also be related to ENSO. The rationale for this is two-fold. Firstly, overseas studies have indicated a relationship between temperature anomalies and ENSO. The 1982-1983 severe ENSO event occurred in parallel with July temperature anomalies in Britain, West Germany and Switzerland (Paliutikof, 1988), and general abnormal warmth across most of North America and Eurasia at latitudes near 50°N (Rasmusson & Wallace, 1983). While this relationship is largely inconsistent, and on many occasions severe winters were experienced during ENSO events in America (Rasmusson & Wallace, 1983), a more reliable relationship exists in Japan. In Western and Central Japan temperatures for July and August are significantly below normal during ENSO events, and air temperatures over most of the country appear to be highly correlated with Sea Surface Temperature (SST) anomalies in the western Pacific (Yoshino & Yasunari, 1988). This suggests that temperature may indeed be related to ENSO, and that the occurrence of anomalous high temperatures in Australia correlated with ENSO.

Secondly, the known impacts of ENSO in Australia are, in theory, conducive to the occurrence of high temperatures. ENSO generates a more variable climate in the area it affects (Nicholls & Wong, 1990; Nicholls, 1988b). The trend for the band of 'cloudiness' to migrate eastward during ENSO (Bureau of Meteorology Pamphlett) has the net result of increasing the diurnal temperature range (Oke, 1987), therefore increasing the frequency of frosts and maximum temperature (Nicholls, 1990). In addition, some of the most severe heatwaves in Australia occurred in parallel with very severe droughts; for example, the heatwave of 1896 (see Chapter 3) was within one of the worst drought periods ever experienced in Australia (Coughlan, 1985). The occurrence of pervasive and intense heatwaves has historically been related to continentality and the existence of stationary high pressure systems within the interior of Australia, conditions which also suggest an interrelationship between drought and heatwaves[1]. This implies, by induction, that a relationship between heatwaves and ENSO may occur.

5.3 Data Sources and Methodology

The number of heatwaves days, according to *Definition* 2 and *Definition 3* (see *Chapter* 2) at Sydney and Broken Hill, and the number of heat-deaths in Australia from 1847 were investigated to ascertain any links between the frequency of heatwaves and ENSO.

These parameters were correlated with years designated as ENSO events in Peru by Quinn *et al.* (1987) and Ropelewski & Halpert (1987), and with the *Southern Oscillation Index* (SOI). The SOI measures the difference in air pressure between Darwin and Tahiti, and is available on a monthly basis from 1882 (data missing September 1892 to December 1895). SOI is generally very low (less than -10) during an ENSO event.

[1] NB. the cause of short localised heatwave events is less well defined and is more likely to relate to subtle changes in local climate.

A mean SOI was computed for the financial year from the monthly SOIs, and *Figure 5.1* shows the distribution of this mean. The mean SOI fell below -10 on several occasions, the most significant being in 1897, 1941 and 1983. During the severe 1982-83 El Niño event, the mean SOI for the financial year was below -20.

McBride & Nicholls (1983) found that the best correlation between SOI and rainfall occurs in spring (September-November) and the weakest in summer. Rainfall for all seasons was, however, significantly correlated with the SOI in the *preceding* season. Because the hypothesis that heatwave incidence is related to ENSO is partly based on the concept that heatwaves are inter-related with droughts, i.e., rainfall, a mean SOI index was calculated for the period June to November, the season preceding the summer season. The distribution of this index is shown in *Figure 5.2*, and in comparison to the mean SOI for the financial year (*Figure 5.1*) exhibits a greater range. According to this index the 1897 ENSO event was as severe as the 1982-83 event.

5.4 Correlating ENSO and Heatwaves

Table 5.1 shows how the number of heatwave days and the number of deaths, per financial year, vary according to the occurrence of El Niño events of varying severity, as defined by Quinn *et al.* (1987) and Ropelewski & Halpert (1987). Comparing El Niño years and non-El Niño years reveals that the number of heat-deaths is higher during El Niño events, but the number of heatwave days at Sydney and Broken Hill do not also increase. At Broken Hill, the average number of heatwave days for both definitions actually decreases in El Niño years, and this result is no different when the severity of El Niño is taken into account (see *Table 5.1*).

The number of heat-deaths show a peak during *Moderate+ El Niños*, when on average, over 100 deaths occur in comparison to an average of 24 in non-El Niño years. The number of heatwave days in Sydney also exhibits this trend, although the increase is nowhere near as dramatic. This analysis tentatively suggests that the existence of an ENSO signal affects the number of heatwave deaths, and possibly the number of heatwave days in Sydney, but that moderate El Niños have a stronger impact than severe El Niños. However, there are inaccuracies inherent in this analysis since assigning intensity is a reasonably subjective endeavour. The application of the SOI enables a more

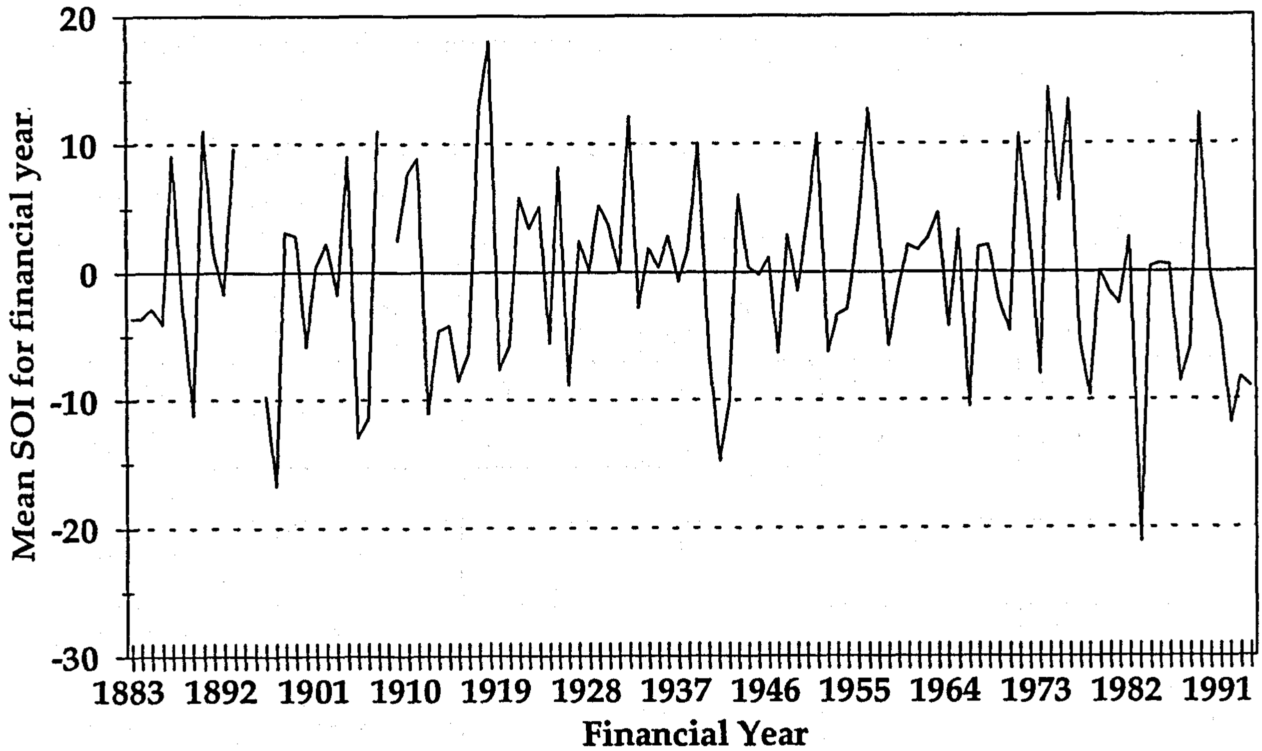


Figure 5.1. Distribution of the Mean SOI by financial year, 1882-1994.

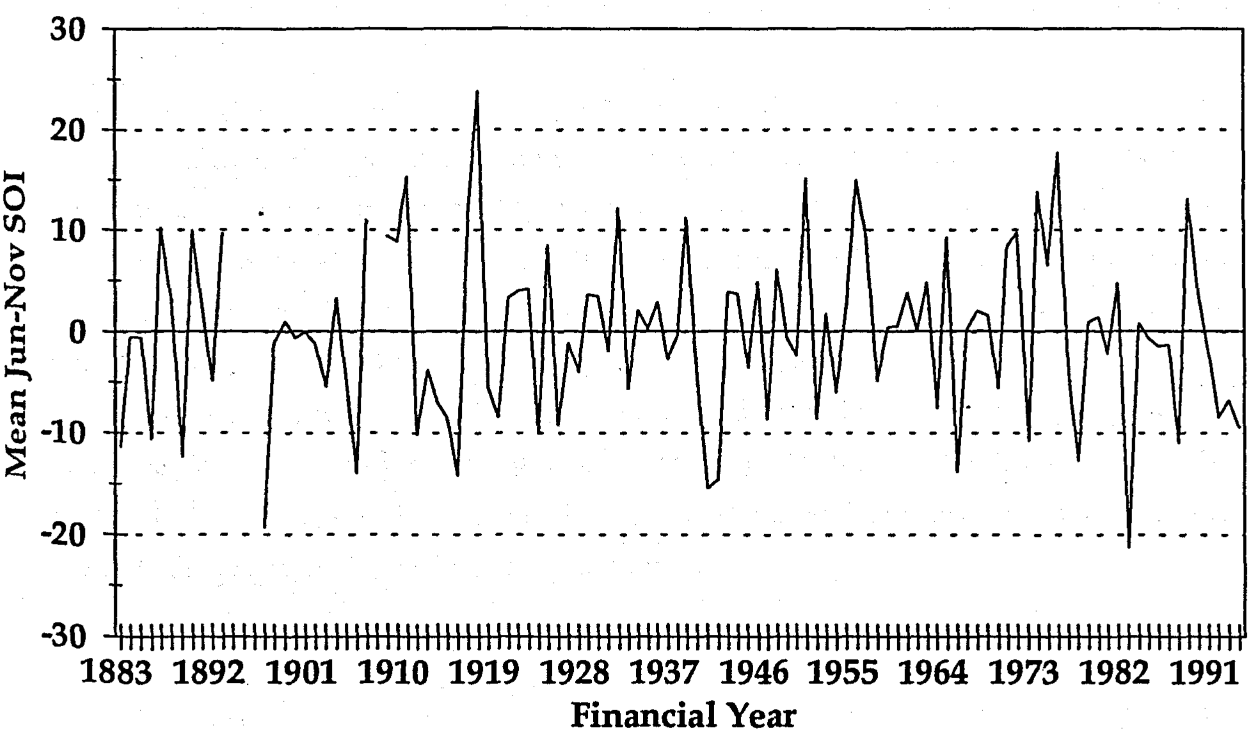


Figure 5.2 Distribution of the Mean June to November SOI by financial year, 1882-1992.

precise quantification of the relationship between heatwaves and ENSO.

Table 5.1: Average number of occurrences of various heatwave indicators and the occurrence of El Niño events.

	Average No. deaths	**Sydney: Definition 2: ≥ 35°C**	**Sydney: Definition 3: ≥ 29.3°C**	**Broken Hill: Definition 2: ≥ 35°C**	**Broken Hill: Definition 3: ≥ 29.3°C**
No El Niño	24	2.9	18.03	32.92	18.84
El Niño	41	3.1	18.1	26.8	14.7
Weak/Moderate El Niño	33.1	2.8	16.2		
Moderate El Niño	11.5	2.9	17.6	23	13
Moderate + El Niño	**102**	**3.9**	**20.8**	**30.5**	**17.5**
Severe El Niño	50.6	3.7	19.3	27	13.7
Severe + El Niño	27	2	16		
Very Severe El Niño	22.6	3.1	18.9		

Figure 5.3, Figure 5.4 and *Figure 5.5* are a series of scatter diagrams, relating the three measures of SOI; monthly, mean annual by financial year, and mean June to November; to the number of heatwave days at Sydney and Broken Hill by financial year according to the two heatwave definitions. For all these measures of SOI, the maximum number of heatwave days actually occurs when the measure of SOI is between -5 and +5, i.e., there is no ENSO signal. In addition, for any given frequency of heatwave days, the SOI is just as likely to be positive as negative. However, the distribution between the frequency of heatwave days defined by *Definition 3* (see *Chapter 2*) with the mean SOI for the financial year and also for June to November, shows a lower number of heatwave days when the SOI index is positive (*Figure 5.4:b,d; Figure 5.5:b,d*).

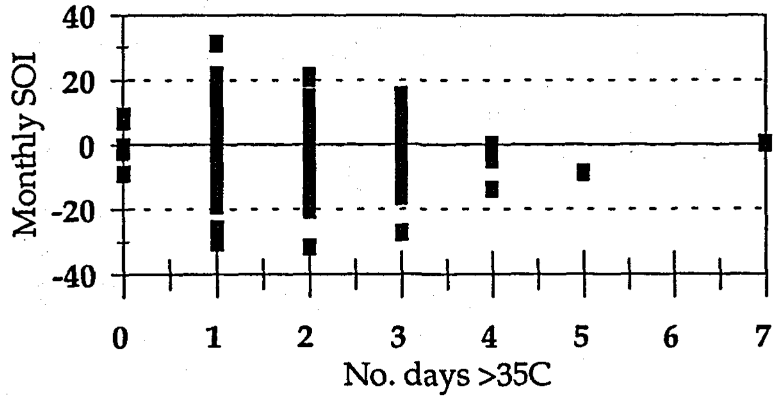


Figure 5.3a Scatter diagram of monthly SOI and the number of heatwave days (*Definition* 2: temperatures above 35°C), at Sydney in that month.

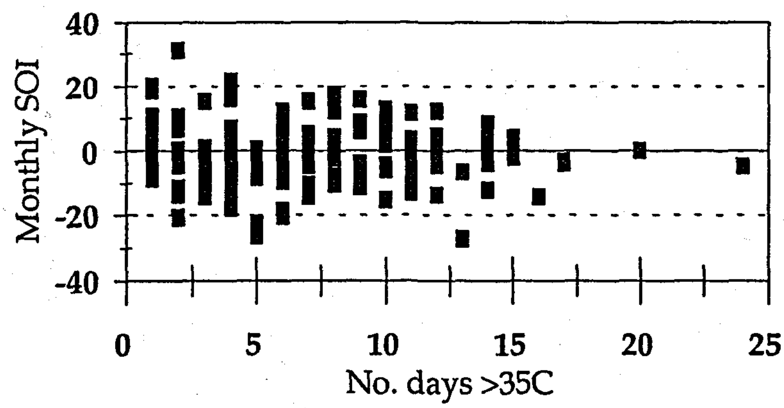


Figure 5.3b Scatter diagram of monthly SOI and the number of heatwave days (*Definition* 2: temperatures above 35°C), at Broken Hill in that month.

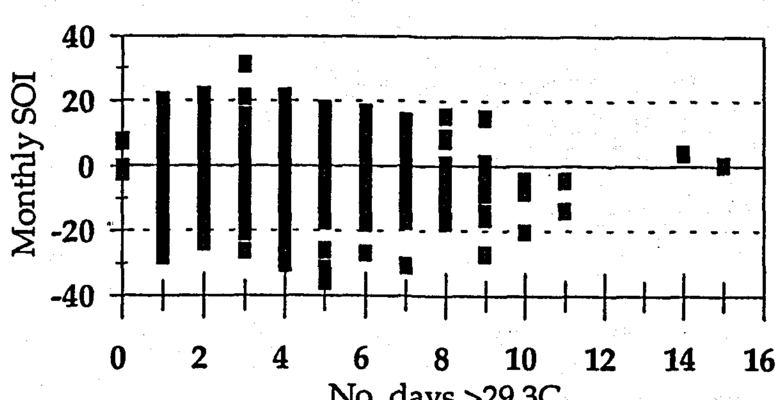


Figure 5.3c Scatter diagram of monthly SOI and the number of heatwave days (*Definition 3*: temperatures above 29.3°C), at Sydney in that month.

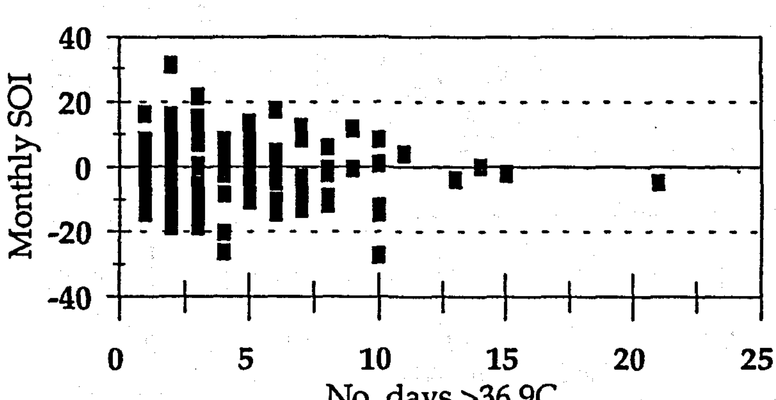


Figure 5.3d Scatter diagram of monthly SOI and the number of heatwave days (*Definition 3*: temperatures above 36.9°C), at Broken Hill in that month.

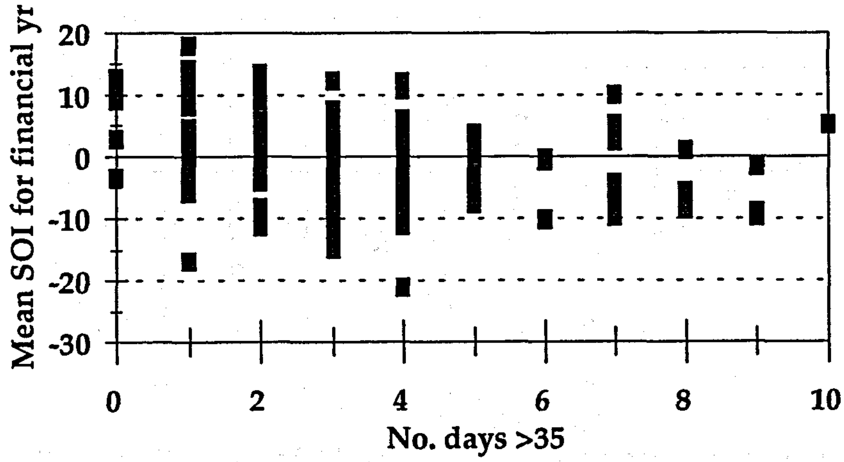


Figure 5.4a Scatter diagram of Mean SOI for the financial year and the number of heatwave days (*Definition 2*: temperatures above 35°C) at Sydney.

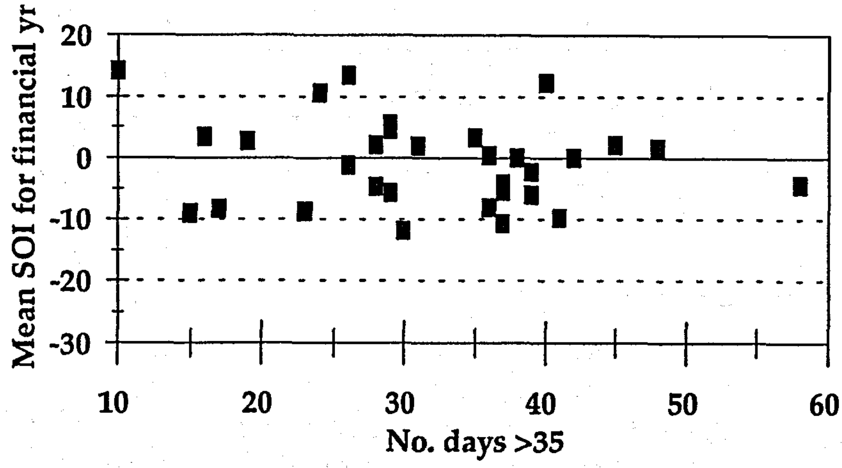


Figure 5.4b Scatter diagram of Mean SOI for the financial year and the number of heatwave days (*Definition 2*: temperatures above 35°C) at Broken Hill.

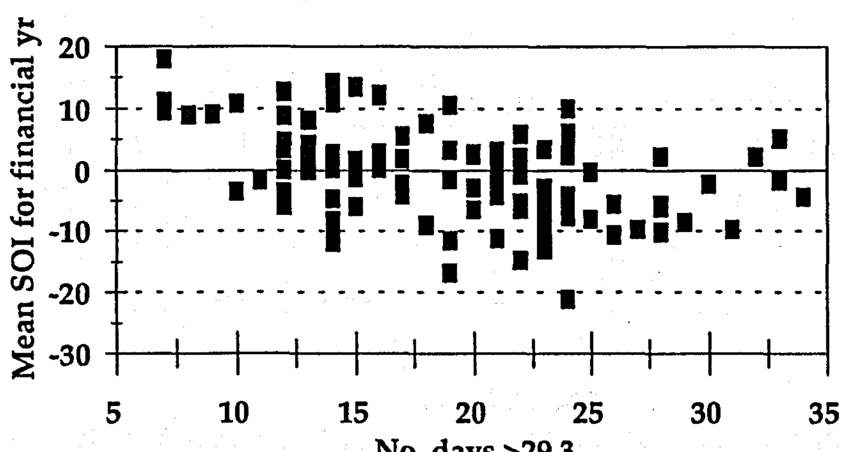


Figure 5.4c Scatter diagram of Mean SOI for the financial year and the number of heatwave days (*Definition 3*: temperatures above 29.3°C) at Sydney.

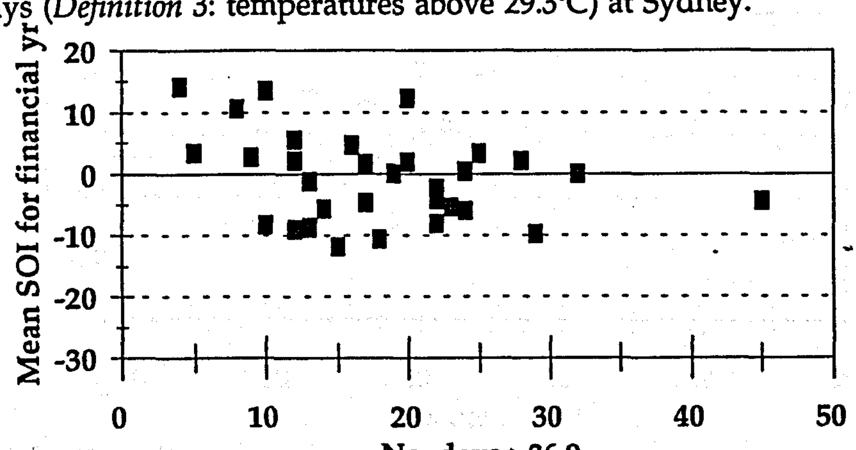


Figure 5.4d Scatter diagram of Mean SOI for the financial year and the number of heatwave days (*Definition 3*: temperatures above 36.9°C) at Broken Hill.

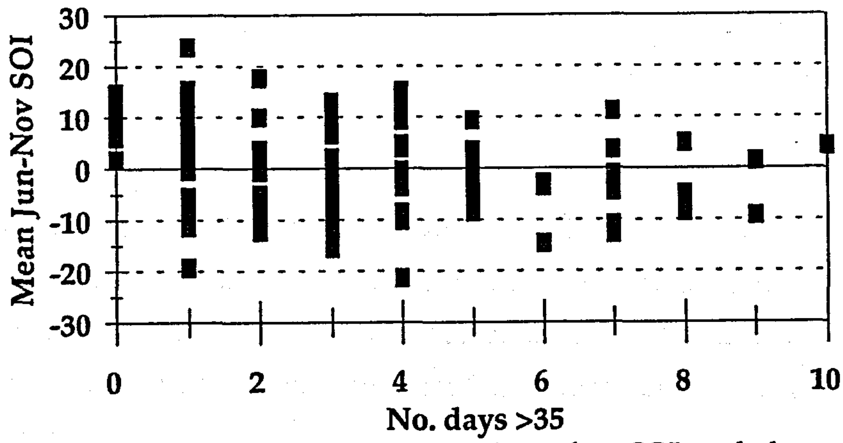


Figure 5.5a Scatter diagram of Mean June to November SOI and the number of heatwave days (*Definition* 2: temperatures above 35°C) by financial year at Sydney.

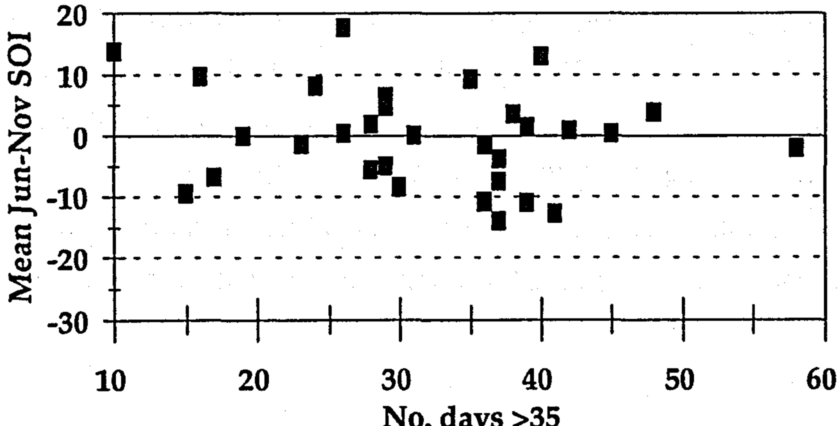


Figure 5.5b Scatter diagram of Mean June to November SOI and the number of heatwave days (*Definition* 2: temperatures above 35°C) by financial year at Broken Hill.

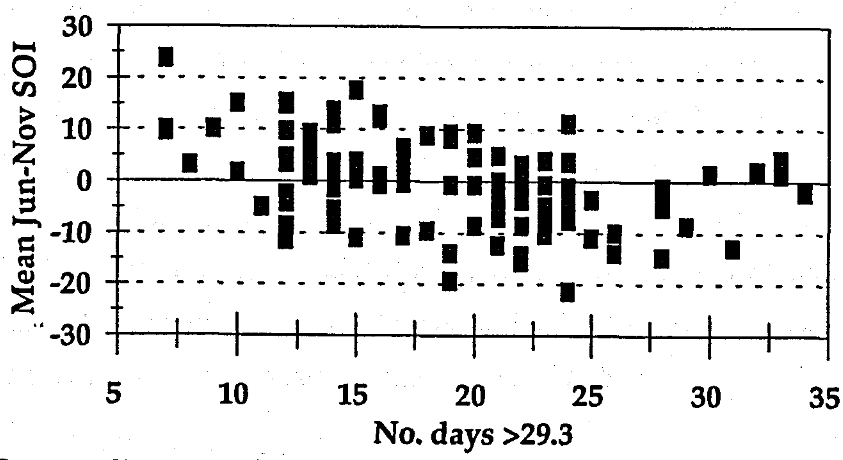


Figure 5.5c Scatter diagram of Mean June to November SOI and the number of heatwave days (*Definition* 3: temperatures above 29.3°C) by financial year at Sydney.

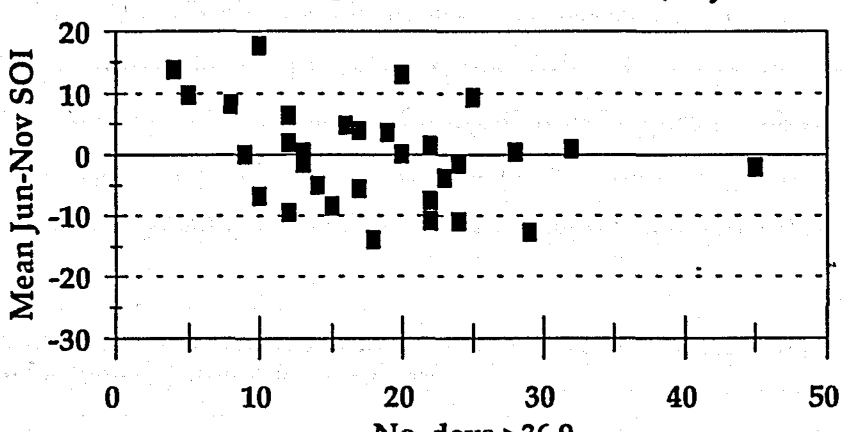


Figure 5.5d Scatter diagram of Mean June to November SOI and the number of heatwave days (*Definition* 3: temperatures above 36.9°C) by financial year at Broken Hill.

The number of deaths by financial year are displayed with the mean SOI and the June to November SOI in *Figure 5.6*, and the distribution pattern is similar to that for heatwave incidence, with larger numbers of heat-deaths occurring when SOIs are between -10 and +10. In contrast to the results exhibited in *Table 5.1*, it does not appear that heat-deaths are related to El Niño.

The severe and extensive heatwaves which occurred in 1896 and 1939, resulting in over 400 fatalities on each occasion, both occurred during ENSO events. These events were designated as moderate plus in intensity by Quinn *et al.* (1987), and are represented on *Figure 5.6* with SOIs of plus and minus 10[2]. It is also likely that these anomalous death rates have skewed the data produced in *Table 5.1* where the highest mortality occurred in moderate plus El Niño events, further confusing a relationship between ENSO and heat-deaths.

There are several inadequacies in this analysis. Firstly, ENSO events last for about 18 months while this analysis focuses an correlations on a yearly basis. Secondly, the number of heat-deaths applied are the total for Australia, while ENSO exhibits varying degrees of influence over the Australian continent, the strongest being in northern and eastern Australia (Nicholls, 1988a). Thirdly, the years designated as El Niño years by Quinn *et al.*, 1987 and Ropelewski & Halpert (1987) are based on records for Peru which do not necessarily coincide with Australian El Niño events. Lastly, the analysis of heatwave days focuses only on Sydney and Broken Hill. Sydney, in particular, is affected by urbanisation and the concurrent micro-climatic influence this exerts (Oke, 1987). This microclimatic process would tend to reduce the impact of ENSO.

5.5 Conclusion

A relationship between ENSO and heatwave frequency would have enabled the prediction of hot summers in the preceding spring (when the onset of ENSO becomes apparent), and the subsequent application of mitigation techniques to relevant population groups. However, only a part of the year-to-year climate variability can be regarded as related to ENSO even in years when ENSO is very strong (Rasmusson & Wallace, 1983), it

[2] The number of deaths that occurred in 1896 is not displayed on Figure 3.7b because SOI data was not available for June to November of that year.

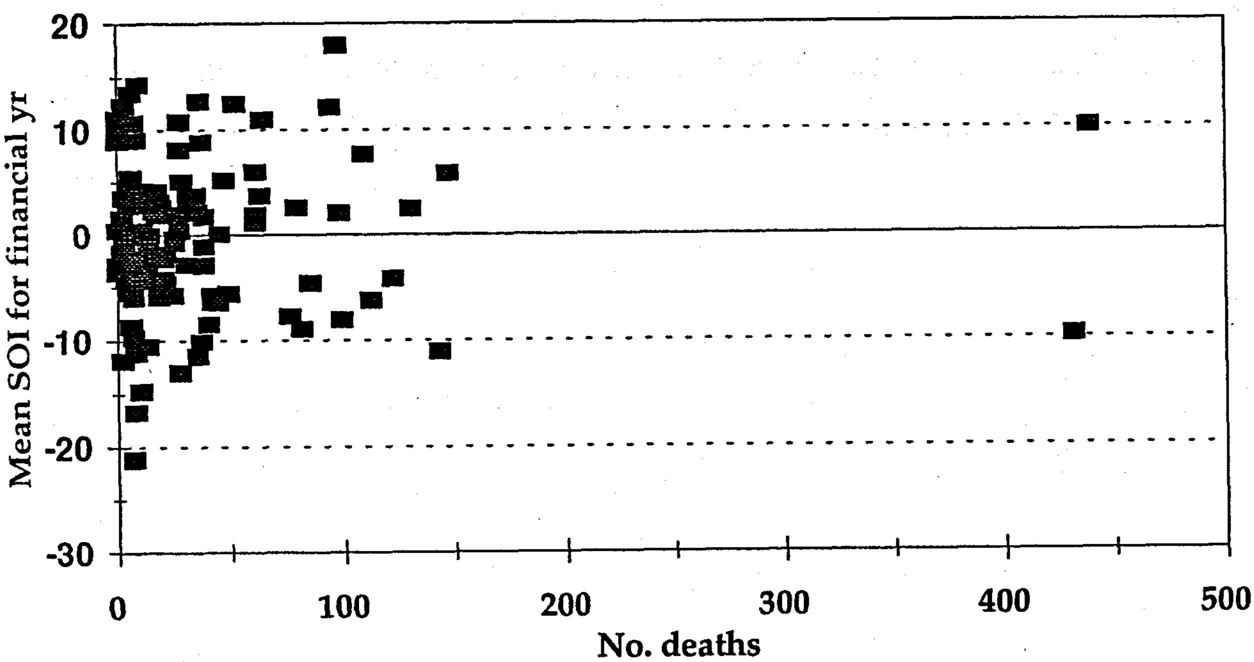


Figure 5.6a Scatter diagram of the Mean SOI for the financial year and the number of heat-deaths by financial year in Australia, 1847-1992.

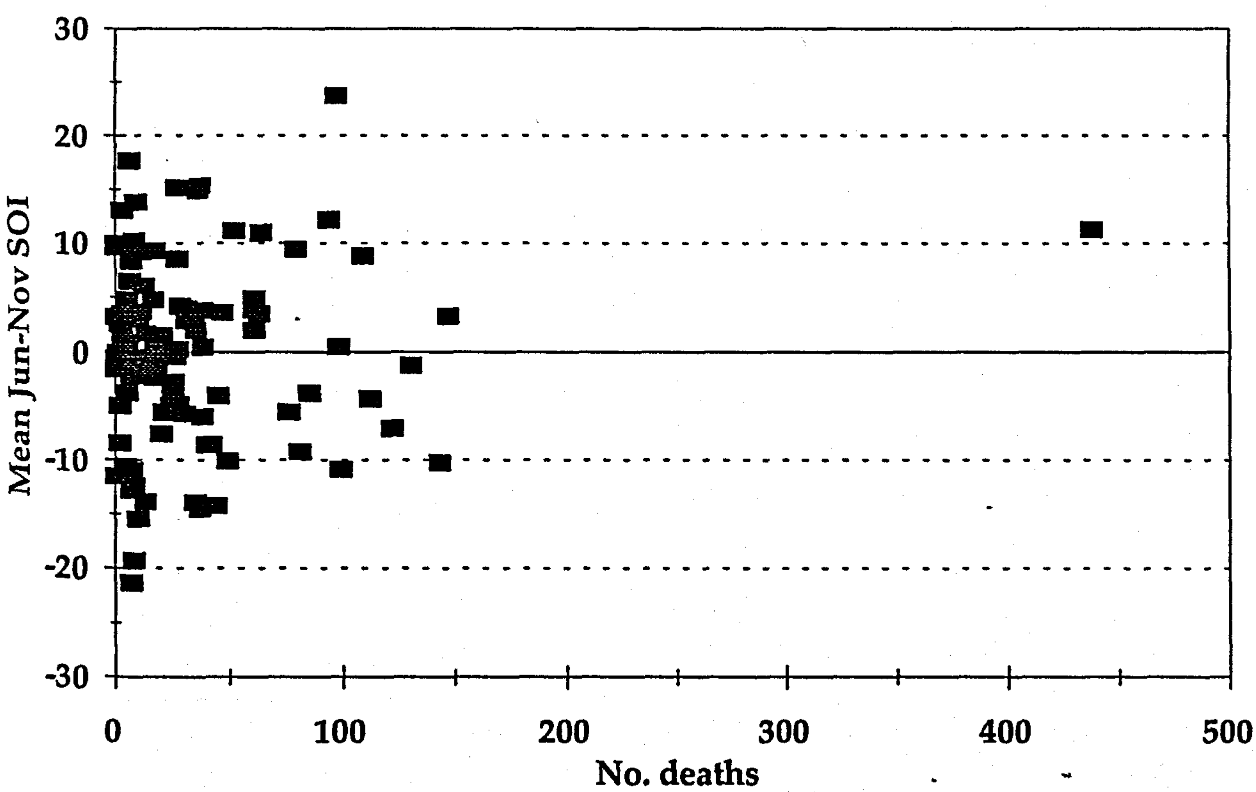


Figure 5.6b Scatter diagram of the Mean June to November SOI and the number of heat-deaths by financial year in Australia, 1847-1992.

appears that no relationship between ENSO and heatwaves exist. The relationship between heatwaves and ENSO requires more detailed analysis before definite conclusions can be drawn, however from this preliminary analysis it would appear that there is no correlation.

Chapter Six
THE RELEVANCE OF HEATWAVES IN THE FUTURE

The consequences of heatwaves on humans and lifelines in Australia have been quantitatively addressed for the first time in this thesis. Heatwaves are probably the most significant natural hazard in Australia in terms of mortality, as indicated in Chapter Three, where vulnerable populations and locations were identified. In Chapter Four, the sensitivity of water and electricity consumption to daily maximum temperatures was substantiated. This chapter aims to place these consequences within the perspective of future climate and social change, by applying the concept that RISK = HAZARD x VULNERABILITY, as discussed in Chapter One. The effect of climate change on heatwave *Hazard* will be integrated with the impact of social changes on *Vulnerability* to gain an understanding of future risk[1].

Where possible, this appraisal will continue the focus on New South Wales, specifically Sydney and Broken Hill. Mitigation techniques will be also be examined.

6.1 Changes to the Hazard of Heatwaves

The Enhanced Greenhouse Effect is projected to result in an average global warming in the range of 0.6 - 1.7°C by 2030 and 1.0 - 3.9°C by 2070 (Mitchell *et al.*, 1994a). *Table 6.1* shows the scenario of temperature change for locations in Australia, and it is clear that the southern and inland parts of the continent will warm to a greater degree than the northern coastal region. In coastal environments, increases in temperature will be moderated by the lagging sea surface temperature (Pittock, 1988; Mitchell *et al.*, 1994a). The range of values represent the optimistic and pessimistic scenarios.

---

[1] Forecasting is an uncertain and inexact science. Any hazard impact projection is only as reliable as the forecast it is based on, in addition to the validity and strength of the assumed relationship between the hazard and its consequences. Furthermore, it is clear that the spatial change in Risk depends on both the relative change in hazard and vulnerability at each location, and that predictions on a large scale are bound to carry the inadequacies of generalisation.

Table 6.1: Scenarios of temperature change for locations in the Australian region. Values for 2030 are rounded to the nearest half degree and those for 2070 to the nearest degree. (Source: Mitchell *et al.*, 1994a: 74).

Region	Local warming per degree global warming (°C)	Warming in 2030 (°C)	Warming in 2070 (°C)
Northern Coast (north of about 25°S)	0.3 - 1.0	0 - 1.5	0 - 4
Southern Coast (south of about 25°S)	0.8 - 1.2	0.5 - 2.0	1 - 5
Inland (more than about 200km from coast)	0.5 - 1.4	0.5 - 2.5	1 - 5

6.1.1 Changes in the magnitude and frequency of extreme temperatures are likely to occur at a greater rate than changes to mean temperature (Mearns *et al.*, 1984; Pittock, 1988; McInnes *et al.*, 1994; Hennessey, 1994). Many of the most significant impacts of climate change will arise from changes in climate extremes (Pittock, 1988; Mitchell *et al.*, 1994a; Hennessey, 1994).

Under a pessimistic scenario, at least a 50% increase in the occurrence of extreme temperatures[2] is predicted (McInnes *et al.*, 1994; Mitchell *et al.*, 1994a,b,c,; Hennessey & Pittock, (in press)). The range of increases projected for Australian capital cities are displayed in *Table 6.2*. While future frequencies of extreme temperatures under the optimistic scenario will not increase significantly at any location, the maximum increase predicted under the pessimistic projection varies from around 40% in Perth and Adelaide to 800% in Darwin. From these figures it would appear that the relative increase in the number of days exceeding 35°C will be greatest in the northern and inland areas. This contrasts with the regional changes in mean temperature displayed in Table 6.1.

[2] Over 35°C or 40°C depending on location. See McInnes *et al.*, 1994; Mitchell *et al.*, 1994a,b,c,; Hennessey & Pittock, (in press) for detailed state-based regional analyses.

Table 6.2: The number of summer (December, January, February) days when maximum temperature exceeds or equals either 35°C or 40°C for Australian capital cities under the present climate and by the year 2030. The range of days for the year 2030 reflects the range of the local warming scenario at each site (Source: McInnes *et al.*, 1994: 23).

City	DJF days ≥ 35°C		DJF days ≥ 40°C	
	Present	2030	Present	2030
Adelaide	11	12-16	1	1-3
Brisbane	3	3-5	0	0-0
Canberra	4	6-9	0	0-0
Darwin	1	2-9	0	0-0
Hobart	1	1-1	0	0-0
Melbourne	8	9-12	1	2-3
Perth	15	17-21	2	3-5
Sydney	2	2-4	0	0-1

Within New South Wales, the change in the frequency of summer days when the maximum temperature exceeds or equals 35°C and 40°C is recorded in *Table 6.3* and illustrated in *Figure 6.1.* At Sydney, an increase in the number of days exceeding 35°C from 2 to 4 is predicted in the pessimistic scenario, with no change in the optimistic scenario. Broken Hill, however, may experience an increase in the frequency of days above 35°C from 25 to 36, and an increase in the number of days above 40°C from 4 to 10. Changes in the incidence of spring days over 35°C are expected to follow a similar pattern (see McInnes *et al.*, 1994:26 for detail).

6.1.2 Changes to the frequency of runs of extreme temperatures have not been evaluated for NSW, however data from Victoria suggest the probability of a 5 day run with temperatures exceeding 35°C will increase by 20-60% (Hennessey & Pittock, in press).

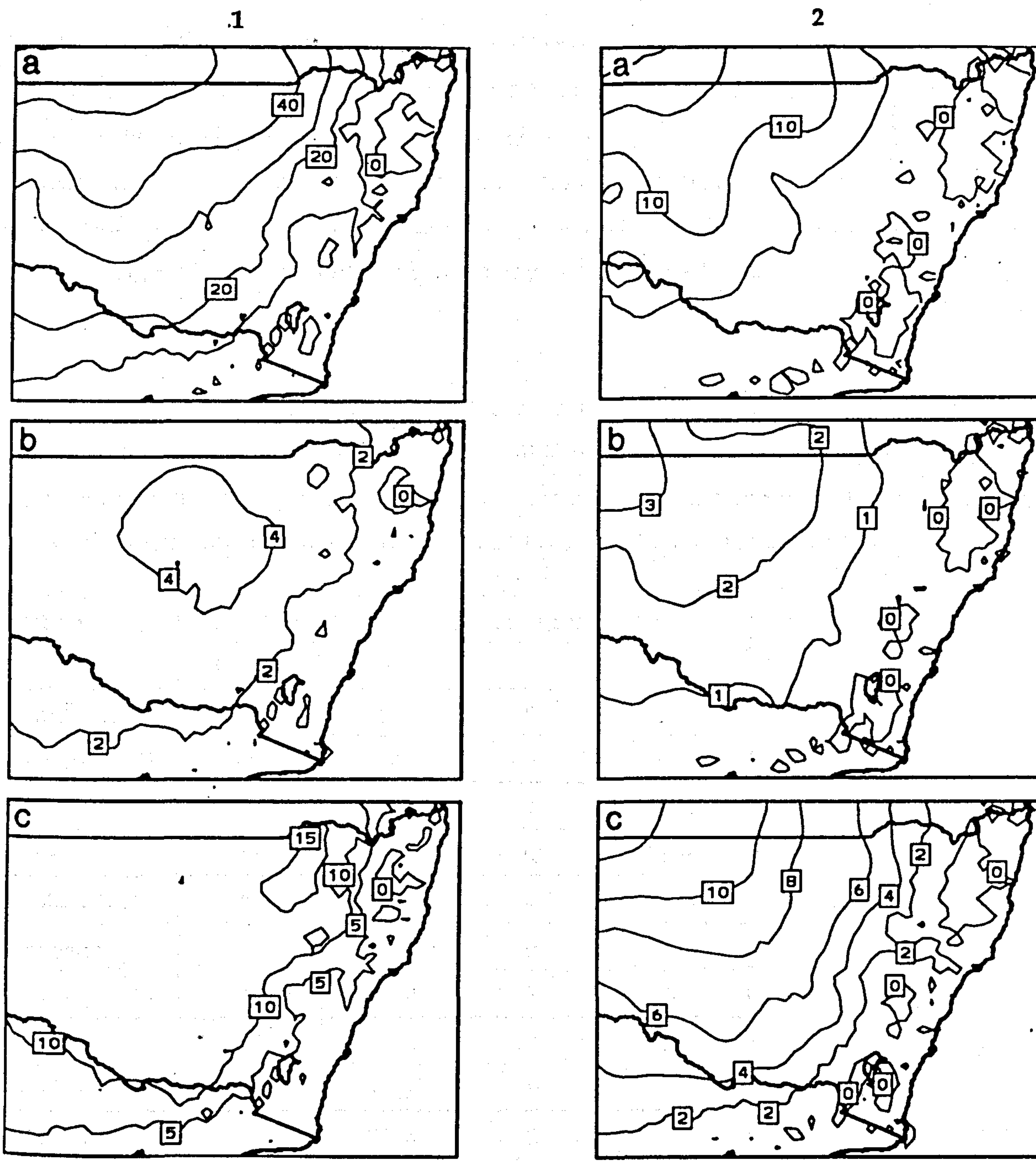


Figure 6.1 A contour plot of the number of summer (December, January, February) days which exceed **1)** 35°C and **2)** 40°C for **a.** the current climate **b.** the change for the optimistic scenario at 2030 and **c.** the change for the pessimistic scenario at 2030. (source: McInnes *et al.*, 1994: 24).

6.2 Changes in Vulnerability to Heatwaves

The analysis undertaken in *Chapter Three* isolated males, the elderly, and to a lesser extent, children in their first year of life as the population groups most vulnerable to heat-death. Labourers and other outside workers are also susceptible. Additional high risk characteristics and groups were discussed in *Section 3.5* and this appraisal will focus on relevant changes to these population groups and risk characteristics.

Table 6.3: The number of summer (December, January, February) days when maximum temperatures exceed or equal either 35°C or 40°C for locations in NSW and ACT, under the present climate and by the year 2030. The range of days for the year 2030 reflects the range of the local warming scenario at each site (Source: McInnes *et al.*, 1994: 23).

Station	DJF days ≥ 35°C		DJF days ≥ 40°C	
	Present	2030	Present	2030
Armidale	1	1-2	0	0-0
Bathurst Gaol	4	5-9	0	0-0
Bega	5	6-8	1	1-2
Bourke	46	51-61	10	13-20
Broken Hill	25	28-36	4	5-10
Canberra	4	6-9	0	0-0
Dubbo	19	22-31	1	2-4
Forbes	21	25-32	2	3-6
Grafton	5	6-11	0	0-1
Griffith	18	21-30	2	3-6
Gundagai	20	23-30	2	3-7
Narrabri	31	34-46	2	2-7
Narrandera	24	26-36	5	7-11
Singleton	17	18-24	3	3-7
Sydney	2	2-4	0	0-1
Tibooburra	50	53-63	15	19-27
Tumbarumba	4	5-20	0	0-0
Young	17	19-25	1	2-4

6.2.1 Changes in the Australian Population relevant to Heatwave Risk

i. *Australia's aging population*

The aging of the Australian population is the most significant trend to affect the vulnerability of the populace to heatwaves. The elderly are the fastest growing demographic group, with the number of individuals over 65 estimated to rise from the present 11% to 22% (5 million people) by the year 2051 (Marthick & Bryant, 1990; Ewan *et al.*, 1991; Clare & Tulpulé, 1994). In addition, the number of 'old old' (75 and over) will increase greatly (Curson, 1991). The number of elderly males in comparison to females will increase as male life expectancy improves (Clare & Tulpulé, 1994).

ii. *Solitary Existence*

The number of elderly living alone will increase from 2.7% to 6.1% by 2051 (Clare & Tulpulé, 1994).

iii. *Chronic Disease*

Chronic illness is already common among elderly Australians, with 75% suffering from one or more long term chronic conditions. Levels of chronic disease and associated medication use, as well as disability and handicap, increase significantly with age, and are likely to increase in the future (Curson, 1989; 1991).

iv. *Migratory Trends*

Based on current trends it is probable that most of Australia's growing population (from accretion and immigration) will be directed towards the major metropolitan areas. A doubling of the population by 2040-50 would undoubtedly manifest itself in a doubling of the population at Sydney and Melbourne, and similar significant increases at other large cities (Curson, 1991). Populations in rural areas seem likely to decline.

There is a trend for the migration of individuals to sunbelt zones and coastal areas, predominantly along the NSW and QLD coast (Curson, 1991).

v. *Socio-Economic Status*

Social and economic marginalisation of sections of the population are likely to increase

(Curson, 1991; Blong 1992).

vi. *Use of Air Conditioning*
Most offices and commercial buildings are already air conditioned, and there is an increasing number of residential dwellings installing air conditioning. Thirty two percent of homes in Australia had air conditioning in 1983, and 35.3% in 1994, and this is expected to increase. The highest penetration into the residential market occurs in South Australia where 63.3% of homes had air conditioning in 1986. In New South Wales, 32.9% had air conditioners at the end of 1986 (ABS, 1986).

6.3 Heatwave Risk in the Future

A schematic interpretation of the influence these changes to heatwave hazard and heatwave vulnerability will exert on future heatwave risk is produced in *Figure 6.2.* Quantifying the relative importance of each factor is difficult. The two trends of the most relevance; the increase in the occurrence of extreme temperatures and the increase in the number of elderly, suggest increased risk, with the finer spatial details influenced by regional climate change and population change. However, future risk is also likely to be influenced by unpredictable 'maverick' factors and potential negative feedbacks, such as the influence of acclimatisation and the role of air conditioning.

6.3.1 Spatial Patterns of Future Risk

The inland of Australia is already a heat island (Dury, 1972), and it seems global warming will increase this dichotomy between coastal and inland areas. This conclusion is exemplified on a regional level for New South Wales where combining *Figure 6.1* with *Figure 3.8*, in *Figure 6.3* indicates that the frequency of extreme temperatures will increase to a greater extent in the historically high risk western zones. Projected movements in population however, will be largely away from these areas to lower risk coastal zones and urban areas.

The effect of increasing urbanisation is complicated. While overseas studies have found higher temperatures within high-density inner-city residential areas in comparison to suburban and rural areas, the sprawling and suburban nature of Australian cities means that the urban heat island effect does not really affect most of the residential population

WHAT WILL HAPPEN IN THE FUTURE.......?

Decreased Risk **Increased Risk**

<-->

CLIMATE CHANGE

?<------------------ • Increase in mean temperature

• Higher frequency of extreme temps ------------------>

• Increased probability of runs of extreme temps------>

SOCIAL CHANGE

• Aging population ------------------------------->

• Increase in the incidence of chronic disease

(and subsequent medication-use increase)------->

• Increase in the incidence of disability

and handicap ---------------------->

?<------------- • North and Coastal Migration --------->?

• Increase in socially and economically

marginalised people ------------------>

• Increase in the number of elderly living alone ---->

?<------------- • Migration of population towards urban centres

?<------------- • Increasing use of Air Conditioners -------->

(potentially problematic if brownouts occur)

Figure 6.2. An interpretation of the influence Climate and Social Change will exert on Future Heatwave Risk.

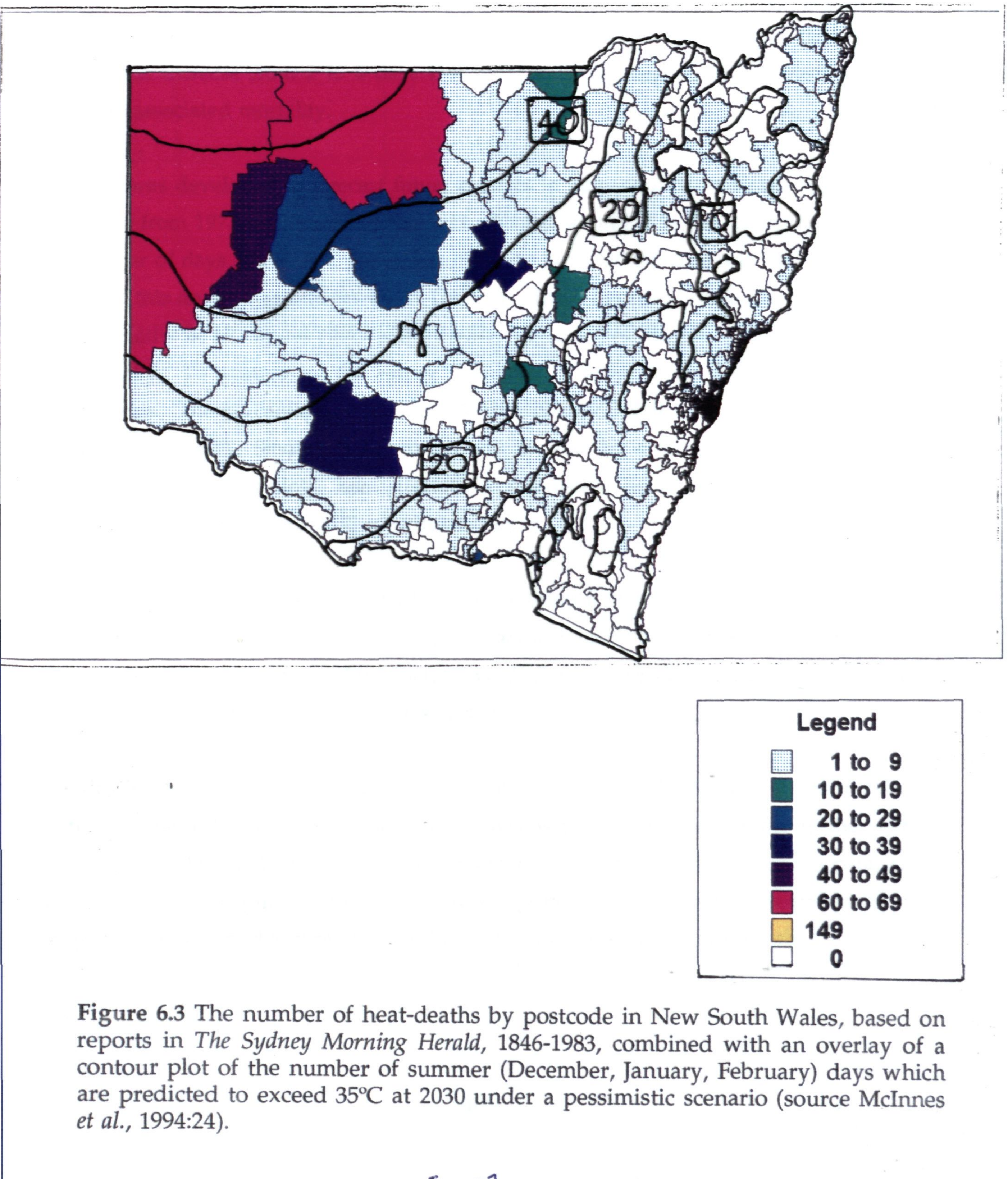


Figure 6.3 The number of heat-deaths by postcode in New South Wales, based on reports in *The Sydney Morning Herald*, 1846-1983, combined with an overlay of a contour plot of the number of summer (December, January, February) days which are predicted to exceed 35°C at 2030 under a pessimistic scenario (source McInnes *et al.*, 1994:24).

(outside working hours). In addition, most of Australia's major cities occupy coastal locations which will probably warm less than inland zones. In New South Wales, the increased heatwave hazard in inland areas may be undermined by the movement of this population towards the coastal urban zone of Sydney and surrounds. Instead of increasing risk, it would appear that in Australia urbanisation will decrease risk.

In Sydney, however, daily mortality rates increase on average by 10% in Sydney in the event of a day with maximum temperature exceeding 35°C. Under the pessimistic scenario the increase from 2 to 4 days will have potentially significant ramifications for heatwave-associated mortality.

A model was developed to forecast future changes in vulnerability on a state basis. The death rate from 1973-1993 for each state was adjusted according to the relative increase in the number of days above 35°C for each capital city projected for 2030 (see *Table 6.1*). The results of this analysis are displayed in *Table 6.4*. These figures indicate that the number of heat-deaths in all capital cities will increase, and that heat-deaths in Darwin will rise substantially. To account for the ageing population, a fudge factor was incorporated in this analysis. The percentage of heat-deaths from 1973-1993 that were in the 65 and over age group was 62%. Since this age group will increase by a factor of two (see *Section 6.2.1*), and the remaining, less susceptible population will consequently decrease relatively, the death rate for 2030 is: calculated by:

> *2030 Death Rate = (current death rate x increment in number of days over 35°C x % population aged 65+ x Increase in proportion of population aged 65+) + (current death rate x increment in number of days over 35°C x % population aged less than 65 x Decrease in proportion of population aged less than 65).*

The death rate adjusted for the aging population is incorporated in *Table 6.4*. Death rates in the Northern Territory may reach over 5 deaths per 100,000 population by the year 2030, up to a five-fold increase on the present rate. There are numerous inaccuracies inherent in this simplistic model, and these figures should only be interpreted as a simplistic prediction, that provides a feel for the relevance of future heat-deaths.

Table 6.4: Projected 2030 death rates per 100,000 for each capital city based on death rate per 100,000 for each state, 1973-93 and predictions in the increase in the number of days above 35°C for each capital city. (* The range represents the optimistic and pessimistic climate change scenarios).

	Death rate per 100,000 for state (1973-93)	Death rate per 100,000 in 2030 *	Death rate in 2030 accounting for an aging population *
Sydney	0.02	0.04 - 0.07	0.03 - 0.06
Melbourne	0.06	0.10 - 0.15	0.09 - 0.11
Brisbane	0.04	0.06 - 0.10	0.05 - 0.08
Adelaide	0.25	0.43 - 0.57	0.34 - 0.45
Perth	0.06	0.11 - 0.13	0.09 - 0.11
Darwin	0.40	1.2 - 5.20	0.92 - 4.12

6.3.2 Unpredictable 'Maverick' factors influencing future Heatwave Risk

If climate change occurs within a respectable timespan, an increase in the mean temperature may prompt the appropriate acclimatisation of the population thereby negating the impact of a relative increase in the frequency of extreme temperatures. However, even in the case of sufficient time for acclimatisation to new mean temperatures, the predicted increase in the frequency of extreme events relative to increases in mean temperature may undermine acclimatisation. The timing of heatwaves in the future may also be relevant to the impact of seasonal acclimatisation for population risk.

Also relevant is the extent to which seasonal acclimatisation is impaired by an overdependence on air conditioning, as individuals spend more time within temperature-controlled environments (Budd, 1990). The real relevance of reduced acclimatisation will depend on the time spent *outside* air conditioned environments by non-acclimatised individuals. The vulnerability of a population existing in air conditioned environments and largely unacclimatised to warmer conditions has been noted by several researchers (Ellis, 1972; Ellis & Nelson, 1978; Schuman, 1972). If power supply was to fail or be rationed during a severe heatwave the unacclimatised populace would loose its first line of defence, and be exposed to high temperatures in un-ventilated buildings (Ellis & Nelson, 1972).

The extent to which living an air conditioned existence detracts from the natural acclimatisation of an individual, modifying their optimum levels of warmth, and the upper levels of warmth which they can be expected to tolerate in an emergency without sustaining ill effects, has still to be determined (Ellis, 1972).

6.4 Consequences of Changes in Hazard and Vulnerability for Lifelines

While this section will focus on the effect of future changes in heatwaves on the lifelines examined in Chapter Four, increases in the frequency and severity of extreme temperature events will have serious ramifications in other areas, most significantly agriculture and bushfire risk (Parry & Carter, 1975; Mearns *et al.*, 1984; Hennessey, 1994).

6.4.1 Transport Links

Heat stress on tracks could increase summertime safety concerns and reduce operational capabilities during heatwaves (IPPC 2). In general the effects of heatwaves on transport links are unlikely to increase significantly in importance.

6.4.2 Water Consumption

Since daily demand for water in Sydney is highly correlated to temperature, an increase in the number of days with high demand is likely under climate change. Because the increase in the number of extreme temperature events for Sydney is small, the effect of this may be minor, although because it will occur in conjunction with an ever increasing population these high demands will occur on top of a growing average consumption. Changes to rainfall and evaporation regimes will be more significant determinants for future water consumption rates (Deen, 1988), influencing not only demand but the availability of supply.

6.4.3 Electricity Consumption

A hotter climate will increase electricity demand for cooling, and refrigerating[3] and decrease demand for heating, probably resulting in a net increase in demand (Coulter, 1988; Lowe, 1988). Summer peak demands are likely to rise, and areas with present

[3] The energy required for heat pumping in refrigerators and freezers is proportional to the temperature difference maintained between the interior and exterior (Lowe, 1988).

annual peaks in winter may convert to summer annual peaks as more electricity is required for air conditioning (Lowe, 1988).

Also of importance is the positive feedback effect that increased electricity production will have on global temperatures. Increased production will result in increased emissions of greenhouse gases, further enhancing the greenhouse effect and global warming.

6.5 Mitigation Techniques

Two extracts from *The Sydney Morning Herald* describing techniques and tactics adopted in the late 19th century to reduce and treat heat stress are shown in *Figure 6.4.* Similar to the campaign employed in December 1896, education campaigns are still utilised in the late 20th century, as excerpts from an Australian and an American pamphlet illustrate in *Figure 6.7.* Education campaigns are of primary importance in reducing heat stress and heat-related deaths, but with all such campaigns their relevance lies in appropriate timing and targeting.

Other mitigation techniques have been evaluated on a performance basis in the United States. The widespread distribution of fans in the 1980 heatwave was not an effective method for the prevention of heatstroke, and indeed fans do not contribute to cooling past temperatures of approximately 37°C (Lee, 1980). Air conditioned shelters are, as a rule, apparently under-utilised (MMWR, 1981; Kilbourne *et al.*, 1982). The merits of air conditioning has been discussed in *Section* 3.5, and appear particularly beneficial in hospitals and nursing homes (Henschel *et al.*, 1968; Marmor 1978). Another successful technique was the instigation of a "heatwave regime" in a New York nursing home which involved the use of light clothing, abstention from physical exercise and outdoor exposure, a light diet and sweat rounds (investigating residents for absence of sweating) (Friedfield, 1949 in Marmor (1978)).

Minimising risk in the future would ideally incorporate sensible planning techniques, such as the avoidance of overcrowding in cities, the provision of parks and other green spaces and sensibly designed offices and residential buildings (Budd, 1990). In high risk areas, monitoring death rates of over 65s has been advocated by Schuman (1972) to enable prior warning of a heatwave epidemic, providing the impetus for the instigation of

"Prevention of Sunstroke: Suggestions for Treatment

A meeting of the Board of Health was held yesterday, Professor Anderson Stuart presiding. The following suggestions for the prevention and immediate treatment of sunstroke were issued for general information:

- *Reduce alcohol*
- *Reduce intake of animal food*
- *Much benefit well result from painting the roof and walls of houses a white colour, and the best possible ventilation must be maintained, especially at night.*
- *It is particularly dangerous to lie upon the hot ground which has been exposed to the sun's rays.*
- *Tight and heavy clothing; exposure to the sun's rays especially if the head, neck and spine be unprotected; undue exertion and fatigue; everything likely to lower the general health and vigour of the body, such as want of rest, dissipation, intemperance, impure air, as from overcrowding and so forth, should all be avoided".*

The Sydney Morning Herald, January 25, 1896: 5e/f.

"Sunstroke: Instructions by the Board of Health:

In view of the very high temperature which has prevailed throughout the colony during the past few days, the Board of Health has had a circular prepared giving instructions for preventing an attack of sunstroke and for the early treatment of cases that may occur. It is being printed in the form of posters to be put up at police stations, post offices, railway stations and other public places, and it is intended afterwards to issue it in pamphlet form along with the posters already issued in regard to snakebite and the treatment of the apparently drowned. The importance of the subject may be gauged by the fact pointed out by the president of the Board of Health that sunstroke caused more than 200 deaths in New South Wales last summer, besides doubtless many others indirectly... The circular is as follows:-....."

The Sydney Morning Herald, December 29, 1896: 5g.

Figure 6.4: Excerpts from *The Sydney Morning Herald* documenting mitigation techniques instigated in the late 19th Century.

Hot Weather Health Emergencies

Even short periods of high temperatures can cause serious health problems. Two common problems are heatstroke and heat exhaustion.

Heatstroke
Heatstroke occurs when your body becomes unable to control its temperature. Your body's temperature rises rapidly, the sweating mechanism fails, and the body is unable to cool down. Body temperature may rise to 106°F within 10-15 minutes. Heatstroke can cause death or permanent disability if left untreated.

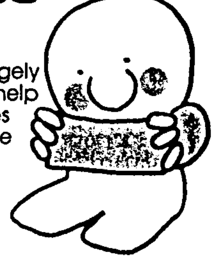
Recognizing heat stroke:
Warning signs of heatstroke include:

- an extremely high body temperature (above 102°F);
- red, hot, and dry skin (no sweating);
- rapid, strong pulse;
- throbbing headache;
- dizziness;
- nausea;
- confusion; or
- unconsciousness.

What to do
If you see any of these signs, you may be dealing with a life-threatening emergency. Have someone call for immediate medical assistance while you begin the following cooling procedures:

Figure 6.5a Exerpt from a CDC (Centre for Disease Control) pamphlet entitled *"Extreme Heat: A Prevention Guide to Promote Your Health and Safety"*.

How to prevent heat illness



The adverse effects of heat waves can largely be prevented if we avoid unnecessary heat, help sweat to evaporate, and replace sweat losses by frequent drinking. Effective ways to achieve these aims are outlined below. Finally, a few safety precautions are recommended.

Avoid unnecessary heat

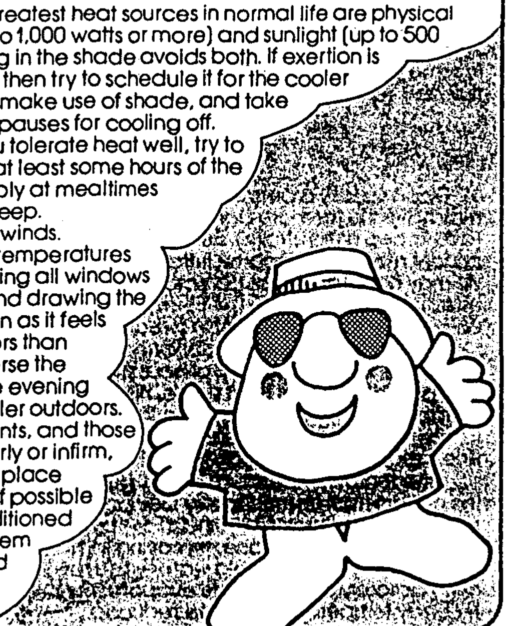
The two greatest heat sources in normal life are physical exertion (up to 1,000 watts or more) and sunlight (up to 500 watts). Resting in the shade avoids both. If exertion is unavoidable then try to schedule it for the cooler times of day, make use of shade, and take frequent rest pauses for cooling off.

Even if you tolerate heat well, try to get relief for at least some hours of the day, preferably at mealtimes and during sleep.

Avoid hot winds.

Keep indoor temperatures down by closing all windows and doors, and drawing the blinds, as soon as it feels hotter outdoors than indoors. Reverse the process in the evening when it is cooler outdoors.

Place infants, and those who are elderly or infirm, in the coolest place available – if possible in an air conditioned room. Give them frequent tepid or cool baths.

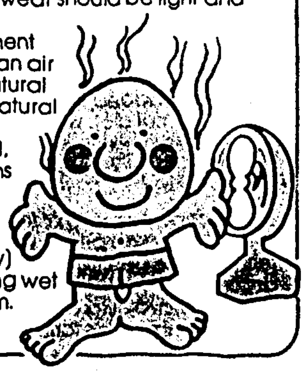


Help sweat to evaporate

Wear as little clothing as possible. Small children do not need any. Whatever clothing you wear should be light and loose to let air circulate.

Use fans to increase air movement over the skin. They are cheaper than air conditioners and do not impair natural acclimatization. Make full use of natural cross ventilation from windows and doors when the breeze is cool, but close the windows and use fans instead when the breeze is hot.

When necessary increase evaporative cooling (especially for infants, invalids, and the elderly) by frequent sponging, or by leaving wet cloths on the skin and fanning them.



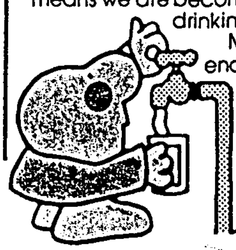
Replace sweat losses

Keep adequate supplies of cooled water always within reach, and drink some at least every hour.

What to drink. The best drink is plain water, cooled to between 15 and 20°C and flavoured or not as desired. Take your normal drinks (tea, coffee, etc.) as well, but avoid excessive alcohol which can itself cause dehydration. Do not take salt tablets or salted drinks ('electrolyte replacers') unless your doctor orders it. Too much salt is harmful, and the normal diet contains enough salts to replace what we lose in sweat.

How much to drink. There is no fixed requirement for extra water in heat waves – it depends on how much we sweat, and that in turn depends on how much heat stress we experience. But few people ever drink enough, because thirst is always satisfied before fluid losses have been fully replaced.

The best guides to our need for extra water are changes in body weight and in the urine. If we lose weight from one day to another, or pass dark and scanty urine, it usually means we are becoming dehydrated and should be drinking more.



Make sure that babies and infants drink enough. They need extra water but they cannot tell you so. Offer them watery drinks at frequent intervals, and dilute any cow's milk given.

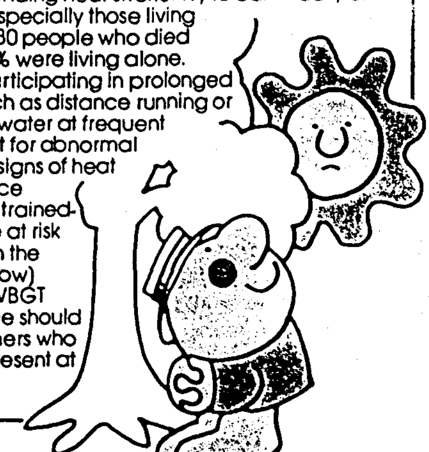
Babies are particularly vulnerable to dehydration, and they have died in heat waves from this cause alone.

Safety precautions in heat waves

Look out for warning signs of heat intolerance (weakness, dizziness, nausea, abnormal behaviour, reduced sweating) in yourself and others. If such signs appear, stop what you are doing and treat them as recommended above.

In nursing homes and hospitals, inspect elderly people every few hours to detect any reduction in sweating, a common sign of impending heat stroke. Try to call in daily on elderly neighbours, especially those living on their own. Of the 280 people who died in one heat wave, 74% were living alone.

If organizing or participating in prolonged strenuous exertion such as distance running or route marches, drink water at frequent intervals, and be alert for abnormal behaviour and other signs of heat intolerance. Experience has shown that highly trained marathon runners are at risk from heat stroke when the WBGT index* (see below) exceeds 25°C. If the WBGT exceeds 28°C the race should be called off. For runners who are less fit the risk is present at lower temperatures.



*WBGT index: a widely used index of heat stress that takes account of air temperature, humidity, wind, and radiant heat. Details can be obtained from the Environmental Health Section, School of Public Health and Tropical Medicine, University of Sydney 2006.

Figure 6.5b Exerpt from a Division of Health and Education, NSW pamphlet entitled *"Take care During Heatwaves"*.

mitigation techniques. Monitoring heat-associated mortality changes may also be appropriate for assessing the effect of long-term changes especially if compared with a baseline study of earlier years such as the analysis presented in *Chapter Three.*

Chapter Seven
CONCLUSION

The aim at the outset of this thesis was to provide a preliminary analysis of the hazard of heatwaves in Australia. For the first time a broad-based appraisal of heatwaves and heatwave consequences in Australia has been produced. This appraisal has been extensive in it's scope, placing the hazard of heatwaves tentatively within the ranks of other well studied natural hazards in Australia, and generating a series of conclusions highlighting areas for further study. This chapter discusses these conclusions and address directions for further study.

7.1 Conclusions

• Heatwaves differ to the short-term dramatic disasters which are the explicit focus of much hazard research. Heatwaves are a pervasive, rather than intensive natural hazard, affecting health and environmental quality rather than generating significant structural damage. Impacts tend to be cumulative instead of sudden. In this manner, heatwaves are similar to droughts.

• There is no official Australian definition of a heatwave. Existing definitions in the literature are diverse, and the application of purpose-specific definitions to the study of heatwave consequences is widespread. Essentially, a heatwave is a subjective experience that is often delineated officially by the media. Three definitions were proposed to represent three broad definitional methodologies: media defined, a universal and a location specific definition. These definitions were then applied to two study sites in New South Wales. Probably the most significant findings of this analysis is the inadequacy of a pervasive heatwave definition, and the difficulties involved in quantifying a subjective experience. Again analogous to droughts, a general and useful definition of a heatwave may be impossible.

• The human impacts of heatwaves have been considerable in comparison to other natural hazards, with over 4,000 heat-deaths occurring as a result of heatwaves in Australia since 1803. It is more than likely that this figure underestimates the real toll. Furthermore, based on the analysis of excess deaths in *Section 3.2* which showed a statistically significant mortality increase during heatwaves in Sydney, it seems probable that the national losses from heatwave-associated mortality are considerable. These findings place heatwaves as the most significant natural hazard in Australia in terms of loss of life.

• Populations susceptible to dying of heat stress are the elderly, males and to a lesser extent, infants less than one year old. Farming, labouring and other outside activities are the most hazardous occupations and activities. While the death rate has declined from over 3 persons per 100,000 in 1908 to the current (1990-92) 0.04 persons per 100,000, rates are still comparatively high among susceptible populations, at over 1 per 100,000 for people aged above 80 years. On a comparative national basis, The Northern Territory presently has the highest per capita incidence of heat-deaths. South Australia is also a relatively high risk location. While most heat deaths occur in January, risk is also high in February in Western Australia, whereas in the Northern Territory heat deaths have a more even annual spread.

• An exploration of the relationship between mortality and maximum daily temperature has resulted in some important conclusions, and many questions. In contrast to American studies, it appears that there is not a one day lag between high temperatures and an increase in mortality rates. Deaths among persons aged above 65 show the most sensitivity to maximum temperature, but it seems likely that additional factors are significant in influencing daily mortality rates.

• With the exception of offensive behaviour offences and general stealing, crime rates were not found to be significantly correlated with temperature. The number of offensive behaviour offences exhibited a definite increase as daily maximum temperature rose.

• While the effects of heatwaves tend to be health-based as opposed to structural, consequences on lifelines have been demonstrated. Water consumption increases significantly with daily temperature in Sydney, and water shortages, restrictions and supply failures have occurred in conjunction with heatwaves. Electricity consumption is increasingly correlated to temperature as the penetration of air conditioners into residential dwellings rises. Transport links, especially railways, have also been affected by heat in the past.

• An ability to predict summers with a high heatwave would enable the instigation of appropriate mitigation techniques to be aimed at the high risk population groups. While there were valid reasons for envisaging a relationship between the occurrence of heatwaves and the El Niño-Southern Oscillation (ENSO) phenomena it appears that no relationship exists.

• The important task of assessing future heatwave risk and consequences has been initiated by integrating conclusions as to vulnerable populations and other heatwave consequences with projected changes in climate and populations. With recognition of the inadequacies inherent in predictive science, it appears that the risk of heatwaves will increase, especially in the Northern Territory, although the subtleties of location are unquantified. Several unpredictable factors may also influence future heatwave risk.

• In summary, this thesis has taken the first step towards the recognition of heatwaves as a significant natural hazard in Australia. The quantification of impacts provides a sense of this significance and has enabled the identification of high risk groups, locations and time periods, thereby encouraging a more comprehensive assessment of heatwave risk in the future.

7.2 Directions for further study

Because this thesis aimed to provide a preliminary analysis of heatwaves in Australia, it has raised a number of questions.

While the application of three definitions of a heatwave to two study sites provided the first step towards an understanding of the complexities involved in heatwave definition, the emphasis on temperature alone in defining what was classified as a subjective experience is inherently inaccurate. The effects of humidity were unquantified, as were additional factors such as wind speed, pollution and other heat stress influences. The next step to follow on from the analysis of the influence temperature has on mortality is a comprehensive investigation of mortality in relation to an appropriate heat-stress index[1]. Investigations of this type may also provide answers to certain questions which the analysis in Chapter Three begs, for example; Why are there so many heat deaths in some years in comparison to other years? An additional quandary is why is there a statistically significant increase in total mortality during heatwaves in Sydney but not at Broken Hill, in contrast to the information presented in *Figure 3.8* which represents western New South Wales, including Broken Hill, as a high risk area for heat deaths.

The first step towards isolating high risk groups in Australia in an empirical manner has been undertaken. What must be done now is to focus this analysis on a regional and individual level in order to further sub-divide risk groups. This would provide a more sophisticated understanding of the processes which influence heat deaths, and enable the targeting of mitigation techniques to the most relevant groups. A thorough approach would involve the incorporation of regional quantification of socio-economic status, air conditioning ownership and other factors relevant to risk discussed in *Section 3.4* & *3.5* with the regional distribution of heat and excess deaths. In addition, analysis of excess death data by the cause of death allows the identification of specific illnesses in Australia which are particularly affected by heatwaves. There is considerable scope for more detailed epidemiological examination in this area.

The relationship between temperature and offensive behaviour is curious, and once again encourages the suggestion of further investigation. Morbidity associated with heatwaves is also a significant area that has not been addressed in this thesis. Analysis of hospital admissions, emergency services and clinic utilisation would comprise a comprehensive appraisal of this.

The investigation of the impacts of heatwaves on lifelines, although not as significant as mortality, poses questions especially when placed in the light of future climate change and population increase. The significance of these findings should perhaps be addressed by relevant industry planners.

In addition, to compile a truly comprehensive analysis of heatwaves in Australia, the

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[1] A recent grant for a similar analysis was secured by the Department of Community Medicine, University of Adelaide, South Australia.

impact on agriculture must be assessed within a hazard framework, and the relationship of heatwaves to other relevant hazards, such as droughts and bushfires, better quantified.

Quantifying future heatwave risk is an ongoing task, as knowledge of climate change and population vulnerability improves. The low correlation with ENSO prompts the question of 'what does influence the occurrence of heatwaves and how will this be affected by future climate change?'. An answer to this question would result in a better understanding of the way heatwave hazard will be affected by climate change, enabling more exact predictions. Since the investigation of ENSO and heatwaves was only directed at Sydney and Broken Hill, analysis at other sites is necessary before definite conclusions can be made on the relationship between ENSO and heatwave frequency.

To keep an eye on potential future changes to heat-related death rates, baseline studies and databases are essential. This thesis has provided a baseline study of national heat deaths, and excess deaths in Sydney and Broken Hill. There is now a need to obtain similar data for other locations, specifically for present and future high risk areas. In this manner further quantification of the significant, but neglected, hazard of heatwaves can be realised and steps towards minimising its impacts undertaken.