** **

VCCCAR Project: Framing Adaptation in the Victorian Context

**Costing the impacts of current climate extremes for key vulnerable sectors in Victoria**

Working Paper

Adriana Keating, John Handmer & Joshua Whittaker

Centre for Risk and Community Safety

RMIT University

ISBN: 978 0 7340 4867 7

August 2013

****

**Preface**

This report is a product of the research project “Framing multi-level and multi-actor adaptation responses in the Victorian context.” Previous working papers in this component analysed the variety of estimates of both the aggregate costs of disasters and the cost of specific climate-related events in Victoria (Keating and Handmer, 2011b) and methodologies for assessing the costs of climate change (Keating and Handmer 2011a). This report extends this work by taking a sectoral approach. Future work on the project will include exploring how the costs estimated here may change under climate change scenarios.

**Authorship**

This report was prepared by Adriana Keating, John Handmer and Joshua Whittaker, Centre for Risk and Community Safety, School of Mathematics and Geospatial Science, at RMIT University.

Additional reviewers’ input included:

**Acknowledgements**

In September 2010, VCCCAR held a workshop with key Victorian government representatives and academics to elicit expert opinion and guidance on the selection of an appropriate methodology for costing current and future climate change impacts in Victoria. Experts at this workshop discussed many of the issues presented in this report and their insights are much appreciated.

**Summary**

Climate change is expected to increase the frequency and severity of extreme events in Victoria. Demand exists, in both government and the private sector, for estimates of the cost of these climate change impacts so that potential abatement and adaptation options can be evaluated in economic terms. In order to estimate how costs related to extreme events will increase under climate change, the current costs of extreme events must first be estimated.

More frequent and severe heatwaves, droughts, bushfires, storms, winds and floods are projected for Victoria. Several studies have looked at Victorian sectoral vulnerabilities to extreme events now and under climate change. While definitions of vulnerability and study focuses differ, there is general agreement that agriculture and health are vulnerable sectors.

There is scant data on the economic impacts of climate anomalies at the sectoral level in Victoria. Pronouncements made in the media about the cost of disasters to certain sectors seem to be made with little or no empirical backing. Economic impact assessment of disasters is an involved process that is rarely undertaken in any consistent manner. Stephenson (2010) undertook a thorough assessment of the cost of bushfires to Victoria, and the raw data from this study was used to produce the estimates presented here on the current cost of bushfires to agriculture and the timber industry. Estimates of these costs under climate change can be found in the subsequent working paper for this series, *Future potential losses from extremes under climate change: the case of Victoria, Australia*.

Using some available data this report makes conservative estimates of the current costs of bushfires to the Victorian agricultural and timber industries, the cost of heatwave mortality to Victoria and the costs of climate anomalies to the Victorian public sector. The report estimates that:

* Bushfire costs the Victorian agricultural industry approximately $42 million per annum. If we include business disruption, the total cost to the Victorian economy is approximately $92 million per annum.
* Bushfire costs the Victorian timber industry approximately $74 million per annum. If we include business disruption the total annual cost to the Victorian economy is approximately $185 million per annum.
* Heatwave mortality in Melbourne results in approximately 330 deaths costs Victoria approximately $1.26 billion annually.
* Climate disasters cost the Victorian public sector approximately $424 million per annum. Note this accounts for direct expenditure in terms of output and asset investments only.

These estimates are generally considered to be underestimates. A comprehensive assessment of sectoral level economic impacts from climate anomalies in Victoria would provide greater backing to climate change adaptation decision-making. Assessments of this type would be drawn from partial equilibrium analysis and would preferably utilise standard economic impact assessment methodologies as outlined in earlier work on this project (Keating and Handmer 2011a).

Many gaps remain in our knowledge regarding options for adaptation to the increased frequency and severity of extreme events under climate change. The literature has canvassed a few options, these relate to both physical and social/institutional changes. The field of climate change adaptation economics is in its infancy and is currently grappling with the complex interactions and uncertainties that confound estimates about the probable costs, benefits and distribution of climate change impacts and adaptation options.

**Contents**

1. Introduction 1

2. Current and future extremes in Victoria 2

3. Victoria’s key vulnerable sectors 6

4. Current cost of climate anomalies in key vulnerable sectors 11

5. Conclusion 18

6. References 20

**List of Tables**

Table 1: Vulnerability to climate change impacts in nine major Victorian sectors

Table 2: Costs of bushfires to Victorian agricultural industry

Table 3: Costs of bushfires to Victorian timber industry

Table 4: Estimated costs of climate related disasters to the Victorian State Budget

**List of Acronyms**

ABARE: Australian Bureau of Agricultural and Resource Economics

ABS: Australian Bureau of Statistics

AEMI: Australian Emergency Management Institute

AUD: Australian Dollars

CFA: Country Fire Authority

CSIRO: Commonwealth Scientific and Industrial Research Organisaiton

IPCC: Intergovernmental Panel on Climate Change

VCCCAR: Victorian Centre for Climate Change Adaptation Research

**1. Introduction**

Climate change is expected to increase the frequency and intensity of extreme climatic events worldwide (IPCC 2007). Events such as bushfires, cyclones, drought, floods, heatwaves and storms are predicted to become more frequent and severe throughout Australia, with impacts varying by region, sector and social group (Henessy et al. 2007; Garnaut 2008). In Victoria, climate change is expected to lead to higher average annual temperatures, more days above 35°C, reduced rainfall and more frequent droughts, more extreme weather events such as storms, high winds and floods, an increase in the number of extreme fire danger days, more frequent bushfires, rising sea levels and storm surges (Department of Premier and Cabinet 2009).

Demand exists, in both government and the private sector, for estimates of the cost of these climate change impacts so that potential abatement and adaptation options can be evaluated in economic terms. Increasing frequency and severity of extreme weather events are expected to be one of the first significant impacts of climate change felt by the people of Victoria. In order to estimate how costs related to extreme events will increase under climate change the current costs of extreme events must first be estimated.

This report sits within the wider Victorian Centre for Climate Change Adaptation Research (VCCCAR) project entitled “Framing multi-level and multi-actor adaptation responses in the Victorian context.” This project includes a work package investigating a “preliminary economic analysis of climate change impacts.” Previous working papers in this series have explored the confounding variety of estimates of both the aggregate costs of disasters and the cost of specific events in Victoria (Keating and Handmer, 2011b), and methodologies for assessing the costs of climate change in Victoria (Keating and Handmer 2011a). This report extends this work by taking a sectoral approach. Future work on the project will include exploring how the costs estimated here may change under various climate change scenarios.

Unfortunately, establishing cost estimates to inform climate change related decision-making is a complex and uncertain exercise. The field is currently in its infancy and the estimates that do exist are plagued by issues around data availability, methodological weaknesses and modelling uncertainty in both climate and impact models (Parry et al. 2009). Estimating the costs of current climate anomalies to Victorian sectors is hampered by a lack of available estimates on the economic impacts of disasters (Keating and Handmer, 2011b). Note that while cost and/or impact estimates are sometimes available for industry specific impacts as a result of a specific climate anomaly (for example the cost of the 2009 heatwave to Victorian infrastructure), these individual numbers are insufficient for the calculation of annualised estimates of the cost of climate anomalies for specific sectors, which is the goal of this report.

This report starts with an outline of the current extremes faced by Victoria, and how these are expected to increase in frequency and severity under climate change. Extreme heat and bushfires are key hazards of concern for Victoria in the coming century. Vulnerability to increased climate anomalies under climate change has been analysed by a few studies, and the results of these are also explored. While definitions of vulnerability and differing study aims and approaches mean no strict agreement is identified, agriculture is consistently identified as a key vulnerable sector (see section 3 below).

Using available data this report makes conservative estimates of the current costs of bushfires to the Victorian agricultural and timber industries, the cost of heatwave mortality to Victoria and the costs of climate anomalies to the Victorian public sector. These estimates are generally considered to be underestimates.

**2. Current and future extremes in Victoria**

This section of the report provides an overview of the major climatic extremes facing Victoria now and in the future. As mentioned above, climate change is expected to increase the frequency and intensity of extreme climatic events in Victoria with the likelihood of more frequent and severe heatwaves, droughts, bushfires, storms, winds and floods.

2.1 Extreme heat / heatwaves

Extreme heat is a major cause of hazard-related fatalities in Australia. Heatwaves have killed approximately 70% as many people as all other hazards combined (Blong, 2004). Severe heatwaves in south-east Australia in 1895, 1908 and 1939 led to particularly large losses of life (QUT 2010). In late January and early February 2009, south-east Australia was affected by an exceptional heatwave that saw records set for both high day and night time temperatures and for the duration of an extreme heat event (Bureau of Meteorology 2009). Melbourne experienced three consecutive days with maximum temperatures over 43°C from 28-30 January and unusually high night-time temperatures. A record-high maximum temperature of 46.4°C was recorded in Melbourne on February 7, when bushfires ravaged the state (Bureau of Meteorology 2009). Some 374 excess deaths were recorded during the heatwave, with mortality rates highest among those aged 75 years or older. This was the seventh deadliest disaster in the world in 2009 (Munich Re 2010). The heatwave also had significant impacts on critical infrastructure, particularly power and transport systems and infrastructure (QUT 2010).

There is no standard definition of heatwave in Australia. The Bureau of Meteorology defines a heatwave as ‘a period of abnormally hot weather lasting several days’ (Bureau of Meteorology 2011a). The Victorian Department of Health states that “a heatwave is generally defined as a period of abnormally and uncomfortably hot weather that could impact on human health, community infrastructure and services” (Department of Health, 2011, pg. 2). The American Red Cross (2011) defines a heatwave as ‘a prolonged period of excessive heat, often combined with excessive humidity’. Notwithstanding the differences in definition, climate change is expected to increase the risk of heatwaves (Hennessy et al, 2007, Wang & McAllister 2011). The IPCC’s Fourth Assessment report notes that heatwaves ‘are virtually certain to increase in intensity and frequency (high confidence)’, with increasing risks to human populations and infrastructure (Hennessy et al. 2007, p. 509).

Melbourne’s current annual average of nine days over 35°C is expected to increase to 12 by 2030, 21 by 2070 and 27 by 2100 under a no-mitigation scenario (Garnaut 2008). Regardless of national or international climate change mitigation commitments, adaptation to increased heatwave stress is required. Following the 2009 heatwave Victoria developed a Heatwave Plan for Victoria (Department of Health, 2011). The development of this plan is an example of adaptation in response to climatic extremes; early warning systems, health system and hospital emergency department preparations, promotion of behavioural change and infrastructure improvements (better designed homes and cities) are all examples of heatwave adaptation options (Wang & McAllister, 2011).

2.2 Drought

Inter-decadal variation in rainfall is a characteristic that has driven the evolution of many Australian ecosystems. Dry times are generally interpreted as ‘drought’ because they interrupt agricultural systems (Smith 2004). The Bureau of Meteorology states that there is no agreed upon definition of ‘drought’ because people use water in many different ways. The Bureau of Meteorology monitors and reports on rainfall deficiencies, however it is the responsibility of the Victorian State Government to declare a Victorian drought in consideration of factors other than rainfall such as agricultural impact, ground water levels and social expectations (Bureau of Meteorology, 2011e).

The ‘Federation Drought’ of 1895-1902 devastated large parts of the country, causing livestock numbers to plummet and the lowest wheat crop yields on record (Bureau of Meteorology 2011b). Severe droughts were experienced across Australia in 1937-45 and 1965-68, with 1967 remaining the driest year on record in Melbourne (Bureau of Meteorology 2011b). The drought of 1982-83 was particularly severe in Victoria, causing dust storms and contributing to the devastating Ash Wednesday bushfires that killed 71 people and destroyed more than 2000 houses. Total losses attributed to the drought exceeded $3 billion (Bureau of Meteorology 2011b).

Since the mid-1990s, the majority of Victoria has experienced severe drought conditions, characterised by the lowest streamflow in approximately 80 years of record (Kiem and Verdon-Kidd 2010). The drought of 2002/03 was estimated to have cost approximately 1 percentage point in GDP growth, despite the fact that the farm sector accounts for only 3.5% of GDP (Horridge et al, 2003). The social and economic impacts of drought have been particularly severe for farming families and rural communities. Although not solely attributable to drought, the number of farming families declined by 9% from 112,800 in 2001 to 102,600 in 2006 (ABS 2006). Employment in the agricultural sector fell by 19% over this period, with the greatest annual fall (14%) coinciding with severe drought conditions in 2002-03 (ABS 2006). Between 2005 and 2007, average cash income for Victorian farms declined by $16,000 to $39,240 per year, while the number of farms with negative cash income increased from 20% to 35% (ABARE 2008).

Climate change is expected to lead to drier conditions throughout the state. Droughts have become hotter since about 1973 due to higher temperatures during periods of rainfall deficiency (Nicholls 2004). A high emissions path would lead to warming of 1.8°C to 3.8°C by 2070, with a rainfall change of -25% to +3%. Warming is likely to be greater in northern regions, while greater drying is expected in southern regions (Department of Premier and Cabinet 2009).

Botterill (2004) tracks the development of drought policy in Australia and describes a change from viewing drought as a natural disaster to a normal feature of Australia’s climate. This policy shift has led to an increasing focus on farm management and resilience, but Botterill (2004) argues that this shift is constrained by a policy landscape influenced by emotive factors and (understandable) sympathy for farm hardship.

2.3 Bushfire

Climate, vegetation and dense settlement make bushfires a particularly destructive hazard in Victoria. There is a close connection between major devastating bushfires and severe droughts. Early events in the state’s history include the 1851 “Black Thursday” fires which burnt about 5 million hectares (one quarter of the state) and resulted in widespread destruction of faming communities, although loss of life was low; the 1939 ‘Black Friday’ bushfires, which burned around five million hectares, claimed 12 lives and destroyed around one million sheep and cattle, and the 1898 ‘Red Tuesday’ fires, which claimed 12 lives and destroyed more than 2000 buildings. Bushfires in 1926 killed 60 people and caused widespread damage to farms, homes and forests, while the 1939 ‘Black Friday’ fires burned around 2 million hectares, claimed 71 lives and destroyed 650 houses. More recent events include ‘Ash Wednesday’ (1983) and ‘Black Saturday’ (2009). The 1983 fires, which as with the other “named fires’ coincided with a severe drought, saw 47 Victorians lose their lives and more than 2000 houses destroyed. Another 28 people were killed in South Australia. In 2009, 173 people lost their lives and 2133 houses were destroyed in fires that burned on Melbourne’s outskirts and in other highly populated areas. The fires burned under the most severe fire weather conditions ever recorded, with a record high maximum temperature of 46.4°C in Melbourne, record low relative humidity and strong winds throughout the state (Bureau of Meteorology 2009; Karoly 2009).

Climate change is expected to increase the frequency and severity of extreme fire danger in south-east Australia. The IPCC’s Fourth Assessment Report states that ‘an increase in fire danger in Australia is likely to be associated with a reduced interval between fires, increased fire intensity, a decrease in fire extinguishments and faster fire spread’ (Hennessy et al. 2007, p. 515). The number of extreme fire danger days in south-east Australia is likely to increase by 15-65% by 2020 relative to 1990 and by 100-300% by 2050 for a high rate of global warming (Lucas et al. 2007; CSIRO 2009). Exposure to bushfire hazard is also set to increase. Victoria’s population is expected to grow by 2.27 million over the 20-year period to 2026, while the number of households is projected to rise by 54.6% from 2006 to 2036 (Department of Planning and Community Development 2009).

Options for adapting to increased frequency and severity of bushfire events in Victoria have not been thoroughly explored to date. The Royal Commission in response to the bushfires of February 7 2009 (VBRC 2009) stresses a need for improved land use planning in the outer metropolitan regions of Melbourne, as well as improved emergency service provision.

2.4 Floods, storms and high winds

Floods, storms and high winds have caused considerable damage in Victoria. Flood types can be loosely grouped into riverine, flash-floods and storm water drainage. Relatively minor flooding as a result of storm-water drain surcharge is not included in flood loss estimates. Long-term average flood damage costs for Victoria are estimated at $350 million per annum, with major regional flooding occurring every 10 to 20 years (Comrie 2011). Riverine flooding has tended to occur in the central, north-east and Gippsland regions, although significant events have occurred in the north and south-west. Major flooding has also occurred along the Yarra, Barwon and Maribyrnong rivers, with flash flooding occurring in urban areas.

One of Victoria’s worst flood disasters occurred in December 1934 when rain in excess of 350mm fell in the catchment for the Yarra River and 140mm fell in Melbourne within 48 hours. The Yarra and other metropolitan rivers and creeks broke their banks, inundating suburban areas and forcing evacuations. The Yarra Valley, South Gippsland and the La Trobe River District were severely flooded, with damages to buildings, livestock and crops exacerbated by gale force winds. 36 people lost their lives in the floods and in Melbourne 400 houses and factories were inundated (Bureau of Meteorology 2011b).

Between September 2010 and February 2011, heavy rainfall associated with a strong La Niña event caused widespread flooding across Victoria. Floods in September 2010 mostly affected rural areas and townships in the state’s west and north-east. Around 35 rivers were flooded, causing damage to farms and houses and forcing thousands to evacuate. Damage caused by heavy rain and strong winds cut power to more than 40,000 homes. Many of the areas affected were flooded again in January and February 2011, in addition to parts of metropolitan Melbourne. Victoria experienced its wettest January on record in 2011, recording a state-wide average of 118.58mm compared to the long-term average of 39.72mm (Bureau of Meteorology 2011c). Significant rainfall and flooding events also occurred during February, including an ‘extreme’ event on February 4 that caused flash flooding across metropolitan Melbourne (Bureau of Meteorology 2011d). Around one-third of Victoria experienced some form of flooding or storm damage between September and February. An estimated 4000 houses were damaged by the floods, in addition to damage and disruption to farms, critical infrastructure and essential services. The floods are estimated to have cost the agricultural sector in excess of $269 million in losses and damages, with lost revenue for the tourism sector at around $176 million (Comrie 2011). Premier Baillieu was widely reported to estimate the cost to infrastructure as being well in excess of $60 billion (Australian Broadcasting Corporation 2011). The estimated gross cost of the floods is in excess of $1.3 billion (Comrie 2011).

Climate change is expected to increase the risk of damaging floods, storms and winds. The IPCC predicts an increase in the frequency of high-intensity rainfall and strong wind events in south-east Australia, with likely increases in associated damages (Hennessy et al. 2007).

Response and adaptation options to increased frequency and severity of flooding in Victoria fall into two broad categories – physical responses and institutional changes (including warning systems). SMEC (2010) suggest that infrastructure could be upgraded to prevent flood damage, and Wang & McAllister (2001) suggest updating building codes and incorporating flood considerations into land use planning. Comrie’s (2011) review of the handling of the 2010-11 Victorian flood warnings and response recommended substantial overhaul of State and local government emergency management in order to improve planning and response coordination, including an expanded flood warning system.

**3. Victoria’s key vulnerable sectors**

3.1 Identifying vulnerable sectors

Climate change is likely to affect key sectors in different ways and to varying degrees. Just as some regions may be more or less affected, some sectors may experience greater exposure to climatic extremes and may have limited capacities to adapt. The identification and costing of likely impacts will enable planning and preparation to minimise impacts on key sectors and facilitate adaptation.

The IPCC has identified a number of sectors that may be vulnerable to climate change in Australia (Hennessy et al. 2007). The IPCC report considers the potential impacts of climate change on: freshwater resources; natural ecosystems; agriculture; forestry; coasts; fisheries; settlements, industry and societies; indigenous people; tourism and recreation; energy; and human health. Hennessy et al. (2007) identify a number of sectors as being particularly vulnerable:

* Agriculture:

Cropping is vulnerable due to potential increases in pests, diseases and weeds and reduced yields, although significant regional differences exist. While moderate yield increases are likely in north-east Australia, cropping is likely to become non-viable at the dry margins of southern Australia if rainfall is reduced substantially or if variability increases significantly. Irrigation-dependent horticulture is also likely to be affected by reduced water availability, while warmer conditions may negatively affect temperate fruit and nuts and lead to the spread of the Queensland fruit fly *Bactrocera tryoni* into southern Australia. Viticulture is also likely to be negatively affected by earlier ripening and reductions in grape quality by 2030. Damage from bushfires to the viticulture industry has seen significant losses in recent years (Stephenson 2010). Pastoral and rangeland farming is likely to be affected by reduced pasture growth,[[1]](#footnote-1) increasing land degradation problems such as erosion and salinity, livestock heat stress, and the increasing southward movement of the cattle tick (*Boophilus microplus*) (Hennessy et al. 2007).

* Tourism and recreation:

While some tourist destinations may benefit from drier and warmer conditions, climate change is likely to have significant impacts on snow-based tourism in south-eastern Australia. For the full range of SRES scenarios, 2020 is likely to see between 5 and 40 fewer days of snow cover per year, a rise in the snowline of between 30 and 165 metres and a reduction in the total snow-covered area of 10 to 40 percent. By 2050 it is predicted that there will be between 15 and 100 fewer days of snow cover per year, a rise in the snowline of between 60 and 570 metres, a reduction in maximum snow-depth of between 10 and 99 percent, and a decline in total snow-cover of 20 to 85 percent. The tourism sector as a whole is likely to face greater risks from increases in hazards such as flooding, storm surges, heatwaves, cyclones, fires and drought (Hennessy et al. 2007).

* Health:

The health sector is likely to be affected by an increase in heat-related deaths and illness, as well as food and water-borne diseases. More frequent and severe droughts may exacerbate mental health risks given the well-documented relationship between drought and mental health issues in rural Australia. Incidences of asthma may also rise if projected increases in bushfire risk lead to more frequent bushfires (Hennessy et al. 2007).

Jones and Webb (2008) assessed the vulnerability of nine major Victorian sectors to climate change. They adopted a qualitative, triple bottom line approach to assessing vulnerability, considering the potential economic, social and environmental impacts of climate change on the following sectors: primary production; minerals and resources; manufacturing; energy; building, construction and infrastructure; tourism and services; water; natural resources and biodiversity; and health. The study considers vulnerability to climate change impacts for 2030 and 2070. The authors argue that by 2030 most vulnerability will be encountered through increases in the frequency and extent of extreme events such as drought, fire, flooding and coastal storm surge, while in 2070 vulnerability will arise from the limits of adaptation being exceeded in a range of systems. They found that although the potential economic impacts of climate change may not be high on a state-wide basis, a high degree of economic impact is possible at the regional scale for the water, manufacturing and primary production sectors. The sectors most vulnerable to social impacts include water (high level of vulnerability), primary production (moderate to high), energy (moderate), natural resources and biodiversity (moderate), and health (moderate). Vulnerability to environmental impacts was found to be greatest in the water (high), natural resources and biodiversity (high) and primary production (moderate) sectors. Table 1 summarises key vulnerabilities identified for each sector.

Table 1: Vulnerability to climate change impacts in nine major Victorian sectors

|  |  |
| --- | --- |
| **Primary production** | Vulnerable to decreases in rainfall and increases in extreme events. Particularly vulnerable activities include irrigated agriculture (drought), forestry (fire) and dairy (to drought and heat). Adaptive capacity may be constrained by socio-economic pressures such as rising land prices, changing land use, water security and associated costs. Jones and Webb note that adaptive capacity is likely to be greater in intensively managed systems than those that are extensively managed, such as forestry and fishing, which are more likely to be subject to climatic constraints. |
| **Minerals and resources** | Low level of vulnerability to fire, flood and storm events on land and at sea. Adaptive capacity is considered high due to the high level of engineering and safety built into systems. |
| **Manufacturing** | Vulnerable to higher costs or reductions in the supply of raw materials due to drought and fire, water shortages and power loss. Adaptive capacity is considered moderate to high on a state-wide basis; however, some regional manufacturing is highly vulnerable to chronic and/or severe water shortages. |
| **Energy** | Low level of vulnerability to drought and fire, as well as increased demand due to periods of extreme heat. The sector is considered highly adaptive. |
| **Building, construction and infrastructure** | Low level of vulnerability to increases in extreme weather events, sea level rise and associated impacts. Adaptive capacity is considered moderate to high due to the potential for retrofitting and changes to construction and planning. |
| **Tourism and services** | Low level of vulnerability overall, with some service industries such as insurance, scientific services and outdoor sport and recreation considered moderately vulnerable. Regional vulnerabilities include snow-based and coastal tourism, rural finance, transport and a range of outdoor and water dependent tourism activities. |
| **Water** | Vulnerability is high for economic, social and environmental impacts, with water shortages affecting a range of sectors including primary production and natural resources and biodiversity. Adaptive capacity is considered moderate, influenced by the sector’s capacity for demand management, options for supply, options for multiple use and re-use, appropriate pricing to fund improvements and the willingness of users to seek innovative social and technical solutions. |
| **Natural resources and biodiversity** | High level of vulnerability, particularly in marine, coastal, estuarine, wetland and alpine environments.Adaptive capacity is considered moderate due to degradation of some ecosystems. |
| **Health** | High level of community vulnerability to heat and cold stress, vector-borne diseases, respiratory problems, and stress and mental illness from prolonged or severe climatic events. Adaptive capacity is considered moderate due to the capacities of ambulance, hospital and community services, although it is noted that the poor and socially isolated may be highly vulnerable. |

*Source: Based on Jones & Webb 2008*

The *Victorian Climate Change Adaptation Plan* (DSE 2013) focusses on a range of possible climate change impacts for Victoria. It discusses the warmer and drier conditions that are expected across the state and the likely increase in the frequency and intensity of extreme events (discussed above). As appropriate for a state government plan, it focusses on risk to spheres of state government responsibility and influence. Throughout the plan the impact of extreme events is central. Of relevance is an identification of particular vulnerability of the agriculture, emergency services and health sectors to extreme events. In addition to the risks posed by drought and other extreme events, the Adaptation Plan notes that agriculture will also be affected by dynamic interactions between climate change, extremes, built infrastructure and global market shifts. The emergency services sector is likely to experience increased demand as a result of a growing population and more frequent and intense weather events.

**4. Current cost of climate anomalies in key vulnerable sectors**

4.1 Data availability

Keating and Handmer (2011b) outline serious limitations with the data available on disaster cost estimates for Victoria and Australia more generally. Very little data is available, and what is available can be skewed and/or misleading. For example, the almost exclusive usage of insurance industry data for costing disasters has led to heavily insured disasters such as storms to appear to be more significant than underinsured disasters such as riverine flooding. Because comprehensive economic impact assessments are rarely carried out estimates are often silent on the costs to ecosystem services and cultural assets, making them grossly conservative. There are even fewer cost estimates or economic impact assessments undertaken at the sectoral level, and as such estimating the current cost of climate anomalies to specific Victorian sectors is piecemeal at best.

While broad event-specific economic impact analyses are on occasion undertaken for large events, pronouncements made in the media about the cost of disasters to certain sectors are seemingly made with little or no empirical backing. Economic impact assessment of disasters is an involved process that is rarely undertaken in any consistent manner. Stephenson (2010) undertook a thorough assessment of the cost of bushfires to Victoria, raw data from this study was used to produce the estimates on the cost of bushfires to agriculture and the timber industry provided below.

4.2 Types of disaster cost

Disaster costs are typically categorised as direct or indirect, and tangible or intangible. Direct costs are those incurred from direct contact with the disaster, such as damage to physical assets. Indirect costs are those that flow on from the direct damages, such as interruption to business or disruption to transport networks (BTE 2001). Tangible costs are born from damage to assets that are traded in the market place and as such have a directly observable market value. Intangible costs refer to damage to things that are valued but not traded in the market place, such as memorabilia, cultural heritage, environmental amenity and ecosystem services (BTE 2001). In the discussion below we highlight what costs are included in our estimates.

4.3 Cost of bushfires to the agricultural industry in Victoria

The Australian Emergency Management Institute’s disasters database (AEMI) lists eight bushfire disasters for Victoria between 1980 and today[[2]](#footnote-2). Agricultural costs for the five largest fires are taken from Stephenson’s raw data. Country Fire Authority (CFA) website lists 21 'major fires' between 1980 and today. Unfortunately only three entries (additional to the fires analysed by Stephenson) have any information on agricultural losses. Agricultural costs are estimated for these three additional fires from limited information available on the CFA website. Note that this is a rough estimation[[3]](#footnote-3). Table 2 below summarises the eight fires for which data are available.

Direct losses to the agricultural industry can have flow-on effects to the wider Victorian economy. For example, when crops are lost freight services are no longer required, resulting in less business for freight operators. This sort of business disruption is difficult to measure without general equilibrium modelling, which is complex and often inappropriate for a bushfire disaster because the impact is small relative to the state or national economy (Keating and Handmer, 2011a). An estimation of business disruption is made using a multiplier of 1.178, as done in Handmer et al (2008).

Table 2: Costs of bushfires to Victorian agricultural industry between 1980 and 2010.

|  |  |  |  |
| --- | --- | --- | --- |
| **Event** | **Estimated direct loss** | **Agricultural business disruption** | **Source** |
| 1983 Ash Wednesday - Victoria only | $205.8 million | $242.4 million | Stephenson 2010/AEMI |
| 1985 Central Victoria and Alpine fires | $29.8 million | $35.1 million | CFA/AEMI |
| 1990 Strathbogie | $1.1 million | $1.2 million | CFA |
| 2000 Dadswell Bridge | $13.1 million | $15.5 million | CFA |
| 2003 Alpine fires - Victoria only | $63.8 million | $75.2 million | Stephenson 2010/AEMI |
| 2005/06 Grampians - Mount Gambier, Wilsons Promontory, Melbourne | $65.6 million | $77.3 million | Stephenson 2010/AEMI |
| 2006/07 Great Divide Complex - Cooma, Melbourne | $173.9 million | $204.8 million | Stephenson 2010/AEMI |
| 2009 Black Saturday - Cooma, Mount Gambier, Warrnambool, Wilsons Promontry, Melbourne | $756.1 million | $890.7 million | Stephenson 2010/AEMI |
|  | **COMBINED TOTAL (thousands)** |
| **TOTAL** | **$1,309 million** | **$1,542 million** | **$2,851 million** |
| **ANNUAL TOTAL** | **$42.2 million** | **$49.7 million** | **$92.0 million** |

*Sources: Stephenson 2010, Australian Emergency Management Institute 2011, CFA 2011.*

*All figures are in 2010 AUD.*

From the 1980s until the present, bushfire has (very conservatively) cost the Victorian agricultural industry approximately $1.3 billion (adjusted to 2010 dollars). This equates to approximately $42 million per annum, although costs are concentrated in years with extreme events. If we include business disruption, the total cost to the Victorian economy is approximately $92 million per annum.

This is likely an underestimation for two main reasons. Firstly, many bushfires are not included in this analysis because of lack of data availability. CFA lists 21 ‘major fires’ between 1980 and today, while only eight are included in this analysis. However the majority of bushfire losses occur in major events; Loane and Gould (1986, pg. 1) estimate that “85% of total losses emanate from an average of less than 1 fire per year out of a total number of about 1000 fires per year larger than 1 ha”.

Secondly, even where some data are available on agricultural losses this is likely an underestimation of the total losses to the agricultural industry. As stated, data from the CFA is particularly limited. Even Stephenson’s (2010) more comprehensive data does not include the cost of livestock starvation due to feed loss after the fire event, time and labour costs for rebuilding and the cost of the impact on environmental services such as water regulation.

Annual costs are expected to increase due to land use changes and increased frequency and severity of severe fire weather under climate change. Whether or not these costs can be ameliorated due to adaptation is a question that has not been thoroughly addressed in Victoria.

4.4 Cost of bushfires to the timber industry in Victoria

There is limited historical data currently available on bushfire induced losses to the timber industry in Victoria. Stephenson’s (2010) estimates direct losses to the timber industry for four major bushfires since 1980 (the fifth fire analysed by Stephenson, Grampians 2005, did not result in significant losses to the timber industry). Similarly to agriculture, we can assume that the majority of loss occurs in severe fire seasons, so while the estimates presented here are likely an underestimation they indicate order of magnitude. Business disruption figures are calculated using a multiplier of 1.485 as done in Handmer et al. (2008).

Table 3: Costs of bushfires to Victorian timber industry between 1980 and 2010.

|  |  |  |  |
| --- | --- | --- | --- |
| **Event** | **Estimated direct loss** | **Timber business disruption** |  |
| 1983 Ash Wednesday - Victoria only | $31.3 million | $46.5 million |  |
| 2003 Alpine fires - Victoria only | $1,462 million | $2,170 million |  |
| 2006/07 Great Divide Complex - Cooma, Melbourne | $727.1 million | $1,080 million |  |
| 2009 Black Saturday - Cooma, Mount Gambier, Warrnambool, Wilsons Promontory, Melbourne | $82.8 million | $123.0 million |  |
|   | **COMBINED TOTAL**  |
| **TOTAL** | **$2,303 million** | **$3,420 million** | **$5,723 million** |
| **ANNUAL TOTAL** | **$74.3 million** | **$110.3 million** | **$184.6 million** |

*All figures are in 2010 AUD. Source: Stephenson 2010.*

Total estimated loss to the Victorian timber industry from 1980 to present is $2.3 billion, or an average annual loss of approximately $74 million. If we include business disruption the total annual cost to the Victorian economy is approximately $185 million. While salvage operations can reclaim some lost timber, these generally incur extensive costs themselves and only reclaim a fraction of the fire damaged assets (Stephenson 2010).

Annual costs are expected to increase due increased frequency and severity of severe fire weather under climate change.

4.5 Cost of heatwave mortality to Victoria

As discussed above, heatwaves contribute significantly to disaster mortality in Australia. The 2003 heatwave in Europe and the 2009 heatwave in southeast Australia have brought the issue to the media’s attention in recent years. People with pre-existing health conditions (including mental illness), the elderly, children, people who work outside and those on low incomes are at greater risk during a heatwave (Hughes & McMichael 2011, Hansen et al 2008, Department of Human Services 2009).

Mortality displacement during a heatwave refers to the phenomenon where some of the mortality attributed to the heatwave would have occurred in the subsequent days or weeks anyway, but was brought forward due to the heatwave. Statistical analysis allows for this phenomenon to be investigated. Nicholls et al. (2008) find that mortality displacement is not a major factor contributing to heatwave deaths in Melbourne.

Bi et al. (2010) provide an overview of a number of studies that have analysed heat-related mortality in Australian cities, and the impact of an increasingly aging population and climate change may have. What stands out from this summary is that there is no standard definition of a heatwave used in statistical analysis, or method of reporting the impacts. Developing a standard definition of heatwave for use throughout Victoria (and potentially Australia) would be beneficial for researchers and policy-makers.

Several studies estimate the current average annual number of heat-related deaths in Melbourne. The lack of a single definition of a heatwave means that estimates vary considerably. McMichael et al (2003) estimates 289 deaths annually; we chose this study to be our baseline for estimation because it is in the same order of magnitude as the widely accepted figures from the February 2009 heatwave.

We extrapolate McMichael’s estimate from 2001 to 2010 accounting for increase in population we come to an estimate of 330 deaths per annum. Using the Department of Finance and Deregulation’s value of statistical life[[4]](#footnote-4) we find that heatwave mortality in Melbourne costs Victoria approximately $1.26 billion annually.

Department of Finance and Deregulation (2008) and Bambrick et al. (2008) note the fact that estimates of statistical value of life are based on the average Australian. We know that the majority of people who die in heatwaves are elderly and/or have a lower health status. This poses a potential problem for the use of the standard value of statistical life when valuing this mortality. However, Alberini et al’s (2002) contingent valuation of willingness to pay (WTP) for mortality reductions in the United States and Canada (populations that are similar in many ways to Australia) found little support for this hypothesis. They find that willingness to pay for avoidance of death is equal or greater when the avoided mortality pertains to an elderly person.

This report is focussed on the cost of mortality only and as such is an underestimation of the costs to the health system and Victoria in general. Most heat-related mortality studies analyse data from major population centres only, however Loughnan et al (2010) found that heatwaves cause increased mortality in ten major population centres in rural Victoria. The estimates presented here relate to Melbourne only, and as such are an underestimation of the total cost of heat-related mortality to Victoria.

Non-fatal heat induced health problems are significant (Bambrick et al. 2008), however costing morbidity is outside the scope of this report. We recommend that further work be conducted on the potential costs to the health sector in particular, because this is of significant interest to the Victorian government.

Heatwaves also have significant impacts outside the health sector. The heatwave of January 2007 saw major electricity disruption across Victoria, Nous (2007) estimates that the total direct cost to the Victorian electricity customers was $235 million (2007AUD). The inclusion of business disruption multipliers brings the total estimated cost to the Victorian economy to approximately $500 million (2007AUD).

4.6 Immediate and direct fiscal impacts of climate anomalies to Victoria

As the frequency and severity of extreme events increases under climate change, so too will the costs to the Victorian public sector. The Victorian Climate Change Adaptation Plan (DSE 2013) identifies emergency services as a vulnerable sector under climate change, partly because of an increasing workload due to increased disasters.

Table 4 below shows Government expenditure on both output and asset initiatives in response to climate disasters since 2002. Note these figures account only for immediate and direct output and asset initiatives; they do not measure requirements for longer term expenditure or impacts on government revenue streams.

Table 4: Estimated costs of climate related disasters to the Victorian State Budget between 2002 and 2011

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Year** | **Event** | **Net output cost (thousands)** | **Net asset cost (thousands)** |  |
| 2002 | Drought | $103,020 | $0 |  |
| 2003 | Bushfire | $201,220 | $44,770 |  |
| 2004 | Bushfire and drought | $198,630 | $45,530 |  |
| 2005 | Drought | $18,760 | $0 |  |
| 2006 | Bushfire and drought | $156,890 | $114,620 |  |
| 2007 | Bushfire, drought and flood | $248,710 | $20,330 |  |
| 2008 | Drought | $120,740 | $0 |  |
| 2009 | Bushfire and drought | $1,054,160 | $175,540 |  |
| 2010 | Bushfire, drought and flood | $1,051,000 | $229,700 |  |
| 2011 | Flood and bushfire | $358,600 | $97,500 | **COMBINED TOTAL (thousands)** |
|  | **Total** | **$3,511,730** | **$727,990** | **$4,239,720** |

*Original nominal values have been converted to 2010 dollars using RBA inflation calculator; 2011 values are in current dollars. Some years include co-funding from Federal sources.*

*Source: Victorian Department of Treasury and Finance, Victorian State Budget Papers and Budget Update 2002-03 to 2011-12.*

From these figures we can estimate that climate disasters cost the Victorian public sector, in terms of output and asset investments $424 million per annum on average. It is likely that this is an underestimation of the total fiscal cost of disasters because it accounts for only immediate disaster-related output and investments, not longer term and more indirect spending. It also does not account for impacts on government revenue streams, such as lost taxation income from lost production.

**5. Conclusions**

Extreme events have shaped Victoria’s history and will continue to shape her future. In particular bushfires in southeast Australia are world renowned for their severity, and this potential is expected to increase under climate change. Estimating the total costs of disasters to Victoria is no straightforward matter, and estimating the costs to particular sectors is a challenge due to a paucity of data.

This paper has outlined the current state of climate anomalies in Victoria and how these are expected to increase in frequency and intensity under climate change. Vulnerability to these events exists in many sectors, and increasing resilience is an ever evolving process for Victorians. This paper has outlined some of the few vulnerability assessments that have been undertaken and identified which industries are thought to be particularly vulnerable.

The analyses of the current costs of climate anomalies to Victorian sectors presented here were selected because a) they pertain to vulnerable sectors, and b) because some cost and impact data exist. These estimates indicate that the costs of climate anomalies to vulnerable Victorian sectors are indeed very significant despite being known underestimates. A comprehensive assessment of sectoral level economic impacts from climate anomalies in Victoria would support climate change adaptation decision-making. Assessments of this type would be drawn from partial equilibrium analysis and would preferably utilise standard economic impact assessment methodologies as outlined in earlier work on this project (Keating and Handmer 2011a).

How and where these costs, that are expected to grow in the future, can be reduced pertains to climate change adaptation. The field of climate change adaptation economics is in its infancy and is currently grappling with the complex interactions and uncertainties that confound estimates about the probable costs, benefits and distribution of climate change impacts and adaptation options.

**6. References:**

Alberini et al. (2002) *Does the Value of a Statistical Life Vary with Age and Health Status? Evidence from the United States and Canada*, Discussion Paper 02-19, Resources for the Future, [www.rff.org/documents/RFF-DP-02-19.pdf](http://www.rff.org/documents/RFF-DP-02-19.pdf) Accessed 5 December 2011.

American Red Cross (2011) Heat waves. Available from: <http://www.redcross.org/portal/site/en/menuitem.86f46a12f382290517a8f210b80f78a0/?vgnextoid=8cc6a5f0f013b110VgnVCM10000089f0870aRCRD>

Australian Broadcasting Corporation (2011) ‘Premier Ted Baillieu discusses Victoria's flood situation’, 7:30 Report 24/01/2011, Reporter: Tracy Bowden, <http://www.abc.net.au/7.30/content/2011/s3120655.htm> Accessed 8 December 2011.

Australian Bureau of Agricultural and Resource Economics (2008) Australian farm survey results, 2005-06 to 2007-08. Commonwealth of Australia: Canberra.

Australian Bureau of Statistics (2006) Agriculture in focus: farming families, Australia, 2006. Available from: [http://www.abs.gov.au/AUSSTATS/abs@.nsf/Latestproducts/7104.0.55.001Main%20Features12006?opendocument&tabname=Summary&prodno=7104.0.55.001&issue=2006&num=&view](http://www.abs.gov.au/AUSSTATS/abs%40.nsf/Latestproducts/7104.0.55.001Main%20Features12006?opendocument&tabname=Summary&prodno=7104.0.55.001&issue=2006&num=&view)=

Australian Emergency Management Institute (2011) *Attorney-General’s Department Disasters Database*, Australian Government, <http://www.disasters.ema.gov.au/> Accessed 1 November 2011.

Bambrick et al (2008) *The impacts of climate change on three health outcomes: temperature-related mortality and hospitalisations, salmonellosis and other bacterial gastroenteritis, and population at risk from dengue*, Garnaut Climate Change Review, [http://www.garnautreview.org.au/CA25734E0016A131/WebObj/03-AThreehealthoutcomes/$File/03-A%20Three%20health%20outcomes.pdf](http://www.garnautreview.org.au/CA25734E0016A131/WebObj/03-AThreehealthoutcomes/%24File/03-A%20Three%20health%20outcomes.pdf) Accessed 5 December 2011.

Barr, N. et al. (2005) *Australia’s farmers: Past, present and future*, Land and Water Australia, Department of Primary Industries, <http://lwa.gov.au/files/products/social-and-institutional-research-program/pr050941/pr050941.pdf> Accessed 8 December 2011.

Bi et al. (2010) ‘The Effects of Extreme Heat on Human Mortality and Morbidity in Australia: Implications for Public Health’, *Asia-Pacific Journal of Public Health* **23**(2) 27S–

36S.

Blong, R. (2004) Natural Hazards Risk Assessment: An Australian Perspective, Issues in Risk Science, Benfield Hazard Research Centre and Risk Frontiers.

Botterill, L. (2004) ‘Government responses top drought in Australia’ Chapter 2 in *Beyond Drought: People, Policy and Perspectives* (eds. L. Botterill & M. Fisher), CSIRO Publishing, Melbourne.

BTE (2001) *Economic Costs of Natural Disasters in Australia*, Bureau of Transport Economics, Report 103, Commonwealth of Australia, Canberra.

Bureau of Meteorology (2009) Special climate statement 17: the exceptional January-February 2009 heatwave in south-eastern Australia. Available from: <http://www.bom.gov.au/climate/current/statements/scs17c.pdf>

Bureau of Meteorology (2011a) Glossary of terms. Available from: <http://www.bom.gov.au/lam/glossary/hpagegl.shtml>

Bureau of Meteorology (2011b) Australian climate extremes. Available from: <http://www.bom.gov.au/lam/climate/levelthree/c20thc/index20.htm>

Bureau of Meteorology (2011c) Victoria in January 2011: wettest on record. Available from: <http://www.bom.gov.au/climate/current/month/vic/archive/201101.summary.shtml>

Bureau of Meteorology (2011d) Victoria in February 2011: one of the wettest on record. Available from: <http://www.bom.gov.au/climate/current/month/vic/archive/201102.summary.shtml>

Bureau of Meteorology (2011e) Living with drought. Available from: <http://www.bom.gov.au/climate/drought/livedrought.shtml>

Cason, B. (2011) *Agricultural data for Australia, Victorian livestock numbers*, AgEc Data, [http://members.iinet.net.au/~rgcason/states/viclivestock.html Accessed 14/11/2011](http://members.iinet.net.au/~rgcason/states/viclivestock.html%20Accessed%2014/11/2011).

CFA (2011) *Major fires*, [http://www.cfa.vic.gov.au/about/history/majorfires.htm Accessed 14/11/2011](http://www.cfa.vic.gov.au/about/history/majorfires.htm%20Accessed%2014/11/2011).

Comrie, N. (2011) Review of the 2010-11 flood warnings and response: interim report. State of Victoria: Melbourne.

CSIRO (2009) Climate change and the 2009 bushfires, CSIRO Submission 09/345 prepared for the 2009 Victorian Bushfires Royal Commission. Available from: <http://www.royalcommission.vic.gov.au/Submissions/SubmissionDocuments/SUBM-002-031-0369_R.pdf>

Department of Finance and Deregulation (2008) *Best Practice Regulation Guidance Note Value of statistical life*, Office of Best Practise Regulation, Australian Government [www.finance.gov.au/obpr/docs/ValuingStatisticalLife.rtf](http://www.finance.gov.au/obpr/docs/ValuingStatisticalLife.rtf) Accessed 27 November 2011.

Department of Health (2011) *Heatwave plan for Victoria Protecting health and reducing harm from heatwaves*, Victorian Government Department of Health, Melbourne, <http://www.health.vic.gov.au/environment/downloads/heatwaveplan_vic.pdf> Accessed 14 December 2011.

Department of Human Services (2009) *January 2009 Heatwave in Victoria: an Assessment of Health Impacts*, Victorian Government Department of Human Services Melbourne, <http://www.health.vic.gov.au/chiefhealthofficer/downloads/heat_impact_rpt.pdf> Accessed 27 November 2011.

Department of Planning and Community Development (2009) Victoria in future 2008: Victorian State Government population and household projections 2006-2036. Available from: <http://www.dpcd.vic.gov.au/__data/assets/pdf_file/0008/32201/DPC056_VIF08_Bro_Rev_FA2.pdf>

DSE (2013) *Victorian Climate Change Adaptation Plan*, Victorian Government, Melbourne.

Garnaut, R. (2008) The Garnaut climate change review: final report. Cambridge University Press: Melbourne.

Guest et al. (1999) ‘Climate and mortality in Australia: retrospective study, 1979–1990, and predicted impacts in five major cities in 2030’ *Climate Research* **13** 1-15.

Handmer et al. (2008) *The cost of fire now and in 2020*, unpublished.

Hansen et al. (2008) ‘The Effect of Heat Waves on Mental Health in a Temperate Australian City’ *Environmental Health Perspectives* **116**(10) 1369-1375.

Henessy, K., B. Fitzharris, B.C. Bates, N. Harvey, S.M. Howden, L. Hughes, J. Salinger and R. Warrick. (2007) Australia and New Zealand. Climate change 2007: impacts, adaptation and vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press: Cambridge. pp. 507-40.

Horridge, M., Madden, J. and Wittwer, G. (2003) *Using a Highly Disaggregated Multi-Regional Single-country Model to Analyse the Impacts of the 2002-03 Drought on Australia*, Centre of Policy Studies Working Paper G-141. Monash University, Melbourne.

Hughes & McMichael (2011) *The Critical Decade: Climate change and health*, Commonwealth of Australia (Department of Climate Change and Energy Efficiency) <http://climatecommission.gov.au/wp-content/uploads/111129_FINAL-FOR-WEB.pdf> Accessed 27 November 2011.

Intergovernmental Panel on Climate Change (2007) Climate change 2007: synthesis report. Assessment of the Intergovernmental Panel on Climate Change. Cambridge University Press: Cambridge.

Jones, R. and L. Webb. (2008) Sectoral and regional vulnerabilities to climate change in Victoria. CSIRO Marine and Atmospheric Research: Aspendale.

Karoly, D.J. (2009) The recent bushfires and extreme heat wave in southeast Australia. Bulletin of the Australian Meteorological and Oceanographic Society 22, pp. 10-13.

Keating, A. and Handmer, J. (2011a) Options for assessing the cost of climate change for adaptation policy in Victoria, VCCCAR Project: Framing Adaptation in the Victorian Context Working Paper 2, <http://www.vcccar.org.au/files/vcccar/Framing_project_workingpaper2_240511.pdf> Accessed 29 November 2011.

Keating, A. and Handmer, J. (2011b) The cost of disasters to Victoria and Australia – No straightforward answers, VCCCAR Project: Framing Adaptation in the Victorian Context Working Paper 3, <http://www.vcccar.org.au/files/vcccar/Framing_project_workingpaper3_210611.pdf> Accessed 29 November 2011.

Kiem, A.S. and D.C. Vernon-Kidd. (2010) Towards understanding hyrdoclimatic change in Victoria, Australia – preliminary insights into the ‘Big Dry’. Hydrology and Earth System Sciences 14, pp. 433-45.

Lucas, C., K. Hennessy, G. Mills and J. Bathols. (2007) Bushfire weather in southeast Australia: recent trends and projected climate change impacts. Consultancy report prepared for the Climate Institute of Australia. Bushfire CRC and CSIRO: Melbourne.

McMichael et al. (2003) *Human Health and Climate Change in Oceania: A risk assessment 2002*, Commonwealth of Australia, [www.health.gov.au/pubhlth/strateg/envhlth/climate/](http://www.health.gov.au/pubhlth/strateg/envhlth/climate/) Accessed 5 December 2011.

Munich Re (2010) *Natural catastrophes 2009, 10 deadliest natural catastrophes*, Geo Risks Research, NatCatSERVICE.

Nicholls, N. (2008) The changing nature of Australian droughts. Climatic Change 63, pp. 323-36.

Nous (2007) *16 January 2007 electricity supply interruptions in Victoria*, Department of Primary Industries, <http://www.dpi.vic.gov.au/__data/assets/pdf_file/0018/10098/071023-Exec-Summary---16-Jan-2007-Incident.pdf> Accessed 5 December 2011.

Parry, M et al. (2009) Assessing the costs of adaptation to climate change, A review of the UNFCCC and other recent estimates, International Institute for Environment and Development and Grantham Institute for Climate Change, London.

PWC (2011) Protecting human health and safety during severe and extreme heat events A national framework, Commonwealth Government (Department of Climate Change and Energy Efficiency), [http://www.pwc.com.au/industry/government/assets/extreme-heat-events-nov11.pdf Accessed 5 December 2011](http://www.pwc.com.au/industry/government/assets/extreme-heat-events-nov11.pdf%20Accessed%205%20December%202011).

SMEC (2010) *Climate Change Adaptation Actions for Local Government*, Department of Climate Change and Energy Efficiency, Canberra, <http://www.climatechange.gov.au/what-you-can-do/~/media/publications/local-govt/localadaption_localgovernment.pdf>

Smith, M. (2004) ‘Living in the Australian Environment’ Chapter 1 in *Beyond Drought: People, Policy and Perspectives* (eds. L. Botterill & M. Fisher), CSIRO Publishing, Melbourne.

Stephenson, C. (2010) *The impacts, losses and benefits sustained from five severe bushfires in south-eastern Australia*, Bushfire Cooperative Research Centre.

Queensland University of Technology (2010) Impacts and adaptation response of infrastructure and communities to heatwaves: the southern Australian experience of 2009. National Climate Change Adaptation Research Facility: Gold Coast.

VBRC (2009) *2009 Victorian Bushfires Royal Commission Report*, Parliament of Victoria,

Melbourne.

Victorian State Budget Papers (2003-2010) *Victorian State Budget Papers*, Past Budget Papers [http://www.dtf.vic.gov.au/CA25713E0002EF43/pages/publications-budget-papers-past-budget-papers Accessed 8 December 2011](http://www.dtf.vic.gov.au/CA25713E0002EF43/pages/publications-budget-papers-past-budget-papers%20Accessed%208%20December%202011).

Wang, X. & McAllister, R. (2011) ‘Adapting to heatwaves and coastal flooding’ Chapter 6 in *Climate Change Science and Solutions for Australia* (eds. H. Cleugh et al.), CSIRO, <http://www.publish.csiro.au/pid/6558.htm>

1. Increases in pasture growth due to rising CO2 concentrations are likely to be offset by reductions in rainfall (Hennessy et al. 2007). [↑](#footnote-ref-1)
2. Dandenong Ranges and Mornington Peninsula fire of 19 Jan 1997, and Linton fire of 2 December 1998 did not have significant impacts on agriculture so are omitted from this analysis. [↑](#footnote-ref-2)
3. CFA reports losses for fencing (km), ‘crop and pasture’ (hectares) and livestock (number). Values for fencing and ‘crop and pasture’ are taken from Stephenson (2010). Livestock losses are estimated to be $84 per animal. This is a weighted average cost of ‘livestock’ for Victoria; weighting is based on percentage livestock populations for Victoria in 2009 calculated from <http://members.iinet.net.au/~rgcason/states/viclivestock.html> and livestock values are taken from Stephenson (2010) CFA also lists '400 farms' and AEMI lists ‘500 farms’ as lost in the 1985 Central Victoria and Alpine fires. Assuming the upper figure of 500 farms this loss is estimated at one year’s lost income. Average Victorian farm income in 1985/86 is assumed to be approximately $51,500, which is estimated from Figure 3 in Barr et al. (2005) and inflated to 2010 dollars. All figures are converted to 2010 dollars. [↑](#footnote-ref-3)
4. Department of Finance and Deregulation (2008) estimates the value of a statistical life to be $3.5 million (AUD2007). This figure is inflated to 2010 dollars to become $3,824,628 for this analysis. [↑](#footnote-ref-4)