

FOUNDATION PAPER | ONE

CLIMATE CHANGE

Victoria:
the science, our people
and our state of play

CONTENTS

INTRODUCTION	05
--------------	----



CHAPTER ONE - VICTORIA AND THE SCIENCE OF CLIMATE CHANGE	10
1.1 What is climate change?	10
1.2 Greenhouse gas emissions are increasing	12
1.3 Climate change risks	16
1.4 Hazards and vulnerabilities for Victoria	18
1.5 Our climate types	27



CHAPTER TWO - BIODIVERSITY AND CLIMATE CHANGE	36
2.1 Biodiversity and ecosystem health	37
2.2 Victorian observations	44
2.3 Observed phenology changes in Victoria	50
2.4 Forest systems: climate change impacts on carbon storage	55
2.5 Responding to climate change	59



CHAPTER THREE - SUSCEPTIBILITY OF THE BUILT ENVIRONMENT	63
3.1 Extreme weather events and our infrastructure	64
3.2 Climate change and the future of Victorian infrastructure	72
3.3 Responding to the challenge	74



CHAPTER FOUR - DROUGHT, FLOOD AND CLIMATE CHANGE	82
4.1 Climate change and a hotter, drier Victoria	84
4.2 Climate change and an increase in more extreme rainfall events	91



CHAPTER FIVE - BUSHFIRES	99
5.1 Bushfires in the landscape	99
5.2 The complexity of impact	103
5.3 Bushfires in a changing climate	106
5.4 Bushfire risks in Victoria	109



CHAPTER SIX - HEATWAVES	117
6.1 The heatwave experience	117
6.2 Impact of heatwaves	119
6.3 Innovation and development	126

CONCLUSION	129
------------	-----

ENDNOTES	130
----------	-----

The warming around Australia is consistent with the global pattern and cannot be explained by natural variability alone.

CSIRO AND THE AUSTRALIAN BUREAU OF METEOROLOGY, STATE OF THE CLIMATE 2012¹

Victoria's climate is naturally variable and severe weather events such as bushfires and floods have occurred throughout history. Climate change may lead to changes in the distribution, intensity and frequency of events like these. Some recent events are consistent with scientific understanding of conditions that may be more likely in a warmer world, compared to natural variability alone. However, it is very difficult to identify the specific causes of individual extreme weather events.

REPORT ON CLIMATE CHANGE AND GREENHOUSE GAS EMISSIONS IN VICTORIA, VICTORIAN GOVERNMENT DEPARTMENT OF SUSTAINABILITY AND ENVIRONMENT MELBOURNE, MARCH 2012²

When I testified before the US Senate in the hot summer of 1988, I warned of the kind of future that climate change would bring to us and our planet. I painted a grim picture of the consequences of steadily increasing temperatures, driven by mankind's use of fossil fuels. But I have a confession to make: I was too optimistic.

My projections about increasing global temperature have been proved true. But I failed to fully explore how quickly that average rise would drive an increase in extreme weather.

In a new analysis of the past six decades of global temperatures, my colleagues and I have revealed a stunning increase in the frequency of extremely hot summers, with deeply troubling ramifications for not only our future but also for our present.

This is not a climate model or a prediction but actual observations of weather events and temperatures that have happened. Our analysis shows it is no longer enough to say global warming will increase the likelihood of extreme weather and to repeat the caveat that no individual weather event can be directly linked to climate change. To the contrary, our analysis shows that, for the extreme hot weather of the recent past, there is virtually no explanation other than climate change.

JAMES HANSEN, DIRECTOR NASA GODDARD INSTITUTE FOR SPACE STUDIES, AUGUST 2012³

Let us pursue the impending energy revolution even more resolutely so that 100% of our energy can be supplied from renewable sources as soon as possible. At least we would not have made any mistakes if – which I doubt – we discovered in a few decades that CO₂ emissions were not responsible for climate change after all. All that we would then have done is trigger the unavoidable changeover to other energy sources somewhat earlier. And we would leave some of that precious raw material called oil for future generations. Let us tackle this industrial change now – we have nothing to lose.

PROF. PETER HÖPPE HEAD OF GEO RISKS RESEARCH/CORPORATE CLIMATE CENTRE, MUNICH RE, 2011⁴

We need to support each other, collaborate and share, push the boundaries, mainstream the issues, communicate better and make reporting more effective.

COMMUNITY MEMBER, SW VICTORIA, MANY PUBLICS: PARTICIPATION INVENTIVENESS AND CHANGE CFES, APRIL 2012⁵

INTRODUCTION

Rigorous analysis and objective reporting of scientific knowledge which includes people, culture and policy is at the core of my approach to environmental reporting.

The State of the Environment Report 2013 (SOE) will be a synthesis of the work of scientists and practitioners and it will provide and integrate material to reflect a localised, Victorian perspective on environmental trends.

In my reporting framework for the State of the Environment report 2013, *Science, Policy, People*⁶ produced in accordance with the section 17 of the *Commissioner for Environmental Sustainability Act 2003* (the Act),⁷ I outlined my intention to deliver a report which would **inform the Victorian community about the health of the natural environment and influence government to achieve environmental, social, cultural and economic sustainability.**

My framework identified an audience for environmental reporting beyond policy makers and legislators - that of a public with an increasingly sophisticated appreciation of environmental issues. This caused me to re-evaluate traditional forms and processes of environmental reporting. Broadening the audience for the SOE also necessitated a change in reporting timeliness. A new urgency has developed in providing information to people about the science, environmental trends and the policy response.

To address these issues I undertook to release three foundation papers as part of the research and engagement process for the production of the SOE report.

This **Climate Change Foundation Paper** outlines climate change impacts in the Victorian context. This paper is published as other rigorous, highly authoritative and leading commentary from Price Waterhouse Coopers *Low Carbon Economy Index 2012*ⁱ, the United Nations *Policy Implications of Permafrost Warming*ⁱⁱ, the World Meteorological Organization *2012: Record Arctic Sea Ice Melt, Multiple Extremes and High Temperatures*ⁱⁱⁱ and the World Bank report *Turn down the heat*^{iv}, each recite scrupulous examinations of the science and impacts of climate change and our role in generating it. In the light of this deeply concerning commentary I am reinforced in the view that this paper is both necessary and timely. The material presented in this paper, reflecting the science and our work and consultation over the last two years is an invitation to consider the questions raised. The issues for consideration are complex and responses will evolve over time, and at all levels. The international community is continuing to work through this complexity, as evidenced in the recent United Nations Framework Convention on Climate Change Doha Conference. The pace for some is too slow, however this does not lessen the need or urgency of continued efforts.

The **Biodiversity and Land Foundation Paper** will focus on managing land for biodiversity outcomes - threats to biodiversity, incentives for private landholders to manage for biodiversity outcomes, monitoring & reporting.

The **Water Foundation Paper** will focus on urban water issues, incorporating integrated water cycle management, water sensitive urban design, stormwater management and innovation.

My framework identified an audience for environmental reporting beyond policy makers and legislators...

i www.pwc.com/en_GX/gx/low-carbon-economy-index/assets/pwc-low-carbon-economy-index-2012.pdf

ii <http://www.unep.org/pdf/permafrost.pdf>

iii http://www.wmo.int/pages/mediacentre/press_releases/pr_966_en.html

iv http://climatechange.worldbank.org/sites/default/files/Turn_Down_the_heat_Why_a_4_degree_centrigrade_warmer_world_must_be_avoided.pdf

Governments can be greatly assisted in their regulatory and decision making processes by independent authorities who provide insights into community aspirations and instructive, balanced comment on the policy process

Purpose of this paper

There are many areas in government and academia conducting research and analysing environmental trends – working to bring the best possible scientific knowledge to our considerations of policy direction and public debate. Each ‘discipline’ is seeking to explain biophysical changes and social dynamics through rigorous scientific inquiry and research processes relevant to it. Interdisciplinary, cross sectoral discussion and community involvement is still evolving and gives societal meaning to the new knowledge and facilitates appropriate actions.

The purpose of this **Climate Change Foundation Paper** is to provide an independent and integrated presentation of some of the impacts of climate change in a Victorian setting. It is not intended to replicate the work which has already been undertaken on climate change impacts, bushfires, floods or infrastructure implications but rather to mine those works for insights and present them in a way which may assist the Victorian community – the broader constituency and audience for environmental reporting – to better understand some of the scientific and policy issues we need to consider as we decide on how best to protect and manage our natural resources.

This foundation paper is intended to encourage a lively and productive exchange of ideas and an ongoing discussion about good and best practice in determining responses to the risks which attend our natural environment and the significant economic, social and cultural role the environment has in the lives of Victorians.

Independent statutory roles, such as mine, have a unique function in our system of government. They stand at a distance from government and, depending on their legislative accountabilities, undertake independent investigations or analysis and provide impartial reports. Governments can be greatly assisted in their regulatory and decision making processes by independent authorities who provide insights into community aspirations and instructive, balanced comment on the policy process. I intend for my reporting functions, and the engagement processes of my office, to provide such a contribution to the Victorian Government.

Our situation as told by the science

Australia’s pre-eminent climate science scholars and reporters, CSIRO and the Australian Bureau of Meteorology (BoM), have now provided the public with two reports on the State of the Climate (2010 and 2012).⁸ They have also provided us with two reports through the South Eastern Australian Climate Initiative (SEACI), which also provides valuable science in the context of climate change and variability in our part of the world.⁹ These documents give us cogent and compelling analysis and commentary on climate change in our region.

Some facts

CSIRO/BoM *State of the Climate 2012* (SOC2012) tells us:

- each decade since the 1950s has been warmer than the previous one
- Australian annual-average daily maximum temperatures have increased 0.75°C
- Australian annual-average daily mean temperatures have increased by 0.9°C
- Australian annual-average overnight minimum temperatures have warmed by more than 1.1°C since 1910.

2010 and 2011 were Australia's coolest years recorded since 2001 due to two consecutive La Niña events which drive temperatures down but, even subject to this phenomenon, 2011 was the warmest La Niña year on record and still warmer than all but one year in the 20th century.

SOC2012 also reports that global average mean sea level rose faster between 1993 and 2011 than during the whole 20th century. Australia is an island continent and our climate is influenced by systems over the Indian, Southern and Pacific oceans. Sea surface temperatures around Australia have increased faster than the global average and in 2010 recorded temperatures were the highest on record increasing by 0.8°C since 1910.

Some projections

SOC2012 states that climate models suggest:

- Australian average temperatures are projected to rise by 1.0 to 5.0°C by 2070 when compared with the climate of recent decades – this means an increase in the number of hot days and warm nights and a decline in cool days and cool nights
- an increase in the number of droughts is expected in southern Australia but it is also likely that there will be an increase in intense rainfall events in many areas
- it is likely that there will be fewer tropical cyclones in the Australian region, on average, but the proportion of intense cyclones is expected to increase.

No regrets

The *Australia State of the Environment 2011*,¹⁰ report attested to real concerns about the changing climate and its impacts on the environment, the economy, and on us. The authors commented:

Climate change is now widely understood as a prime risk to both our environment and our society.

Australia is an island continent and our climate is influenced by systems over the Indian, Southern and Pacific oceans. Sea surface temperatures around Australia have increased faster than the global average and in 2010 recorded temperatures were the highest on record increasing by 0.8°C since 1910.

This is a no-regrets strategy – what do we have to lose by being cautious in our consumption, production and waste?

In the Australia State of the Environment 2011 report we also read that our 'highly developed economy places us in a good position to reduce our emissions and undertake climate change adaptation'. An example of action we might take to reduce emissions is presented in the *Low Carbon Growth Plans* produced by ClimateWorks Australia.¹¹ These plans suggest that we can still take meaningful action to arrest emissions, but also note that the issue is pressing and that this is the critical decade in which to effect serious, sustained change.

Other commentary from multiple reputable and prestigious observers - Global Climate Leadership Review 2012,¹² Organisation for Economic Co-operation and Development (OECD)¹³ - argues that it makes good fiscal, social and environmental sense to intelligently and purposefully address climate change risks.

This is a no-regrets strategy – what do we have to lose by being cautious in our consumption, production and waste? What do we have to lose if, as a community, we start to consider how to adapt to changing climate conditions?

Outline of the paper

In this foundation paper I have set myself the task of examining some of the hazards and vulnerabilities associated with climate change for our state and how we might consider addressing them. Victoria's greenhouse gas emissions profile is presented, however, this foundation paper does not interrogate mitigation. Rather, it should be viewed as having a focus on adaptation, noting that the concepts are not mutually exclusive and in the future will increasingly merge.

We commence in **Chapter One** with a discussion of climate science and its application to Victoria. To do this we work from the Intergovernmental Panel on Climate Change (IPCC) scenarios and CSIRO climate modelling to map outcomes. Climate change impacts, potential future climates for Victoria and possible scenarios are also presented.

In **Chapter Two** we examine some of the direct and indirect impacts of climate change on biodiversity and primary production.¹⁴ We consider the issues associated with Victorian climate change and the pivotal role of citizen scientists in recording what is happening. We also look at the movement of species associated with climate change, impacts on marine and coasts, phenology, carbon storage.

The key messages from this chapter of the paper are that a changing climate will have a deleterious impact upon our natural environment, and in impacting 'ecosystem services' there will be a commensurate impact upon us as well.

In **Chapter Three**, which we have called the 'Susceptibility of the Built Environment', we look at some of the impacts, both direct and indirect, and the cascading outcomes on infrastructure should we continue with

a business as usual mindset. The ‘cascading’ impacts are the issues of grave importance in this chapter and the conclusions we form attest to the need to consider our actions now. We also consider strategies for adapting our infrastructure to a changing climate - for example demand management is used to explain a “soft” strategic approach.

Having examined some of our vulnerabilities to climate change we also investigate the hazards - drought and floods, bushfires and heatwaves in the remaining chapters.

Chapter Four provides a discussion of the impacts of flood and drought with a focus on regional Victoria (water regulation and supply issues will be addressed in the SoE).

In **Chapter Five** we discuss responding to the risk of increased likelihood of bushfire, fire ecology, human health impacts, reducing exposure, the need for accurate and current information, fire mapping and communicating fire risk (fire management responses and fire regimes will be addressed in the SoE).

Chapter Six presents the impacts of heatwaves on people and biodiversity and discusses some of the innovations in reducing exposure, predominantly in urban landscapes.

The vulnerabilities and hazards I have elected to present in this foundation paper are the result of my consideration of scientific knowledge and research and my extensive community and technical consultation process.

Every chapter of this foundation paper develops significant contemporary ideas for consideration. The paper does not purport to present all ideas or solutions. New ones are being continually developed. What is important is that our responses to the impacts of climate change be integrated into what we build for ourselves and envisage for future generations.

Finally, I would like to thank all of the departments, agencies, scholars, technical specialists and community members who have met with me, and my office, as we developed this foundation paper. I would also like to acknowledge Professor Dave Griggs of the Monash Sustainability Institute for his insightful comments. And, in particular I would like to acknowledge Harvey Stern and Robert Dahni from the Bureau of Meteorology and Leanne Webb, Penny Whetton, Craig Heady and John Clarke from CSIRO for their work in the development of the future climate classes for Victoria presented in Chapter One of this foundation paper.

Professor Kate Auty PhD, MEnvSc, Dip Int Env Law (UNITAR), BA(Hons)LLB, GAICD

Commissioner for Environmental Sustainability

The ‘cascading’ impacts are the issues of grave importance in this chapter and the conclusions we form attest to the need to consider our actions now.



CHAPTER ONE - VICTORIA AND THE SCIENCE OF CLIMATE CHANGE

Policy settings, advances in innovation and technology and social responses will all influence our future climate.

In this chapter we consider climate change science and examine a number of potential impacts in Victoria through the prism of the IPCC emission scenarios - alternative images of how the future climate might unfold, influenced by how much we, as a global community, are willing to change our dependence on fossil fuels. Policy settings, advances in innovation and technology and social responses will all influence our future climate.

As part of our research process we asked CSIRO to provide us with Victorian climate change data from 23 global climate models.¹⁵ BoM then determined how these will reflect future climate classes in the state. This work has not been previously undertaken and the results are presented in section 1.5 of this chapter.

The chapter concludes with a discussion of CSIRO's climate analogues. This work demonstrates a potential future climate scenario for Victorian towns and cities. It poses the critical question - should we look at those analogous regions now in order to review and potentially adopt different agricultural and human settlement practices?

1.1 What is climate change?

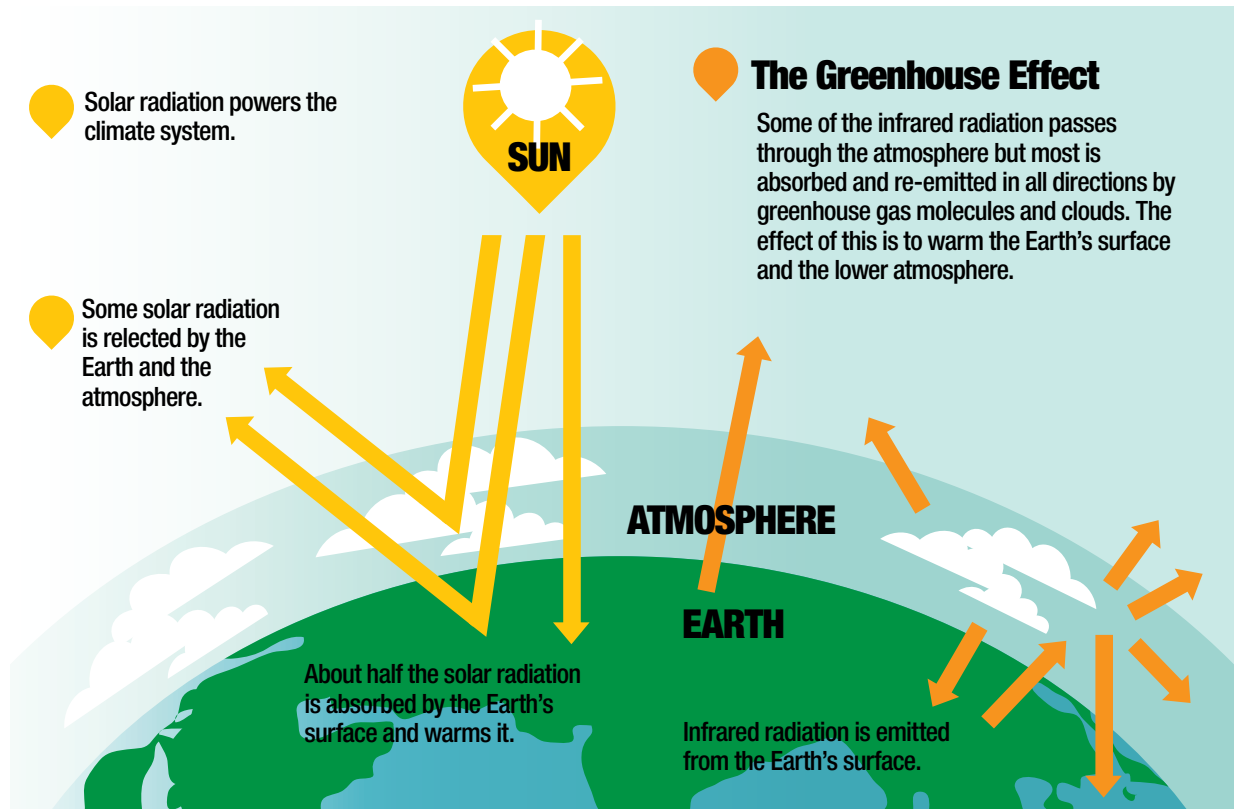
Global climate change is a complex issue and our scientific understanding of it is increasing all of the time as research continues.

The United Nations Framework Convention on Climate Change 1994, provides the following definition:

"Climate change" means a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods.¹⁶

The IPCC provides the following explanation of the contributions of human activity on climate change in comparison to natural processes.

Human activities contribute to climate change by causing changes in Earth's atmosphere in the amounts of greenhouse gases, aerosols (small particles), and cloudiness. The largest known contribution comes from the burning of fossil fuels, which releases carbon dioxide gas to the atmosphere. Greenhouse gases and aerosols affect climate by altering incoming solar radiation and outgoing infrared (thermal) radiation that are part of Earth's energy balance. Changing the atmospheric abundance or properties of these gases and particles can lead to a warming or cooling of the climate system. Since the start of the industrial era (about 1750), the overall effect of human activities on climate has been a warming influence. The human impact on climate during this era greatly exceeds that due to known changes in natural processes, such as solar changes and volcanic eruptions.¹⁷ (Figure 1).



Solid scientific evidence supports the position that climate change is caused by emissions of greenhouse gases. Although there is a great deal of natural variability in global temperatures there are clear fingerprints of human-induced climate change. These are seen in phenomena that would not occur if rising temperatures were not tied to human activity and were purely natural.

It is difficult to directly attribute a single “climate/weather event” to climate change but extreme weather events are increasing. The exceptional will become common – rainfall records will be broken more regularly, droughts and bushfires will be more frequent and intense. However, as further research is undertaken and data sets are expanded it is foreseeable that scientists will more readily be able to attribute single climate events to climate change.¹⁹

Estimating the magnitude of temperature increase over time is highly dependent on scenarios of human emissions creation (see below). In its last report, the IPCC estimated that mean global temperature increases this century were likely to be in the range 1.8-4.0°C, depending on emissions scenarios. In Australia, CSIRO estimates that the range of temperature increase is between 1-5°C.²⁰

Commonly we hear the suggestion that limiting global warming to two degrees will allow us to avoid the worst impacts of climate change. There is growing evidence however that this is not the limit for acceptable climate change, rather it is the threshold between dangerous and “extremely dangerous” climate change.²¹ Because warming above this threshold is within the bounds of possibility, we must be prepared to consider more severe impacts from warming.

“ ... [I]f carbon dioxide emissions suddenly stopped, global temperatures would stop growing but would not drop significantly for at least 1000 years. It would take centuries to remove the carbon dioxide that has already accumulated in the atmosphere, and allow for the slow release of heat that is already stored in the oceans”.²²

Figure 1: IPCC’s diagrammatic representation of the greenhouse effect. IPCC FAQ 1.3. An idealised model of the natural greenhouse effect. Modified by CfES.¹⁸

1.2 Greenhouse gas emissions are increasing

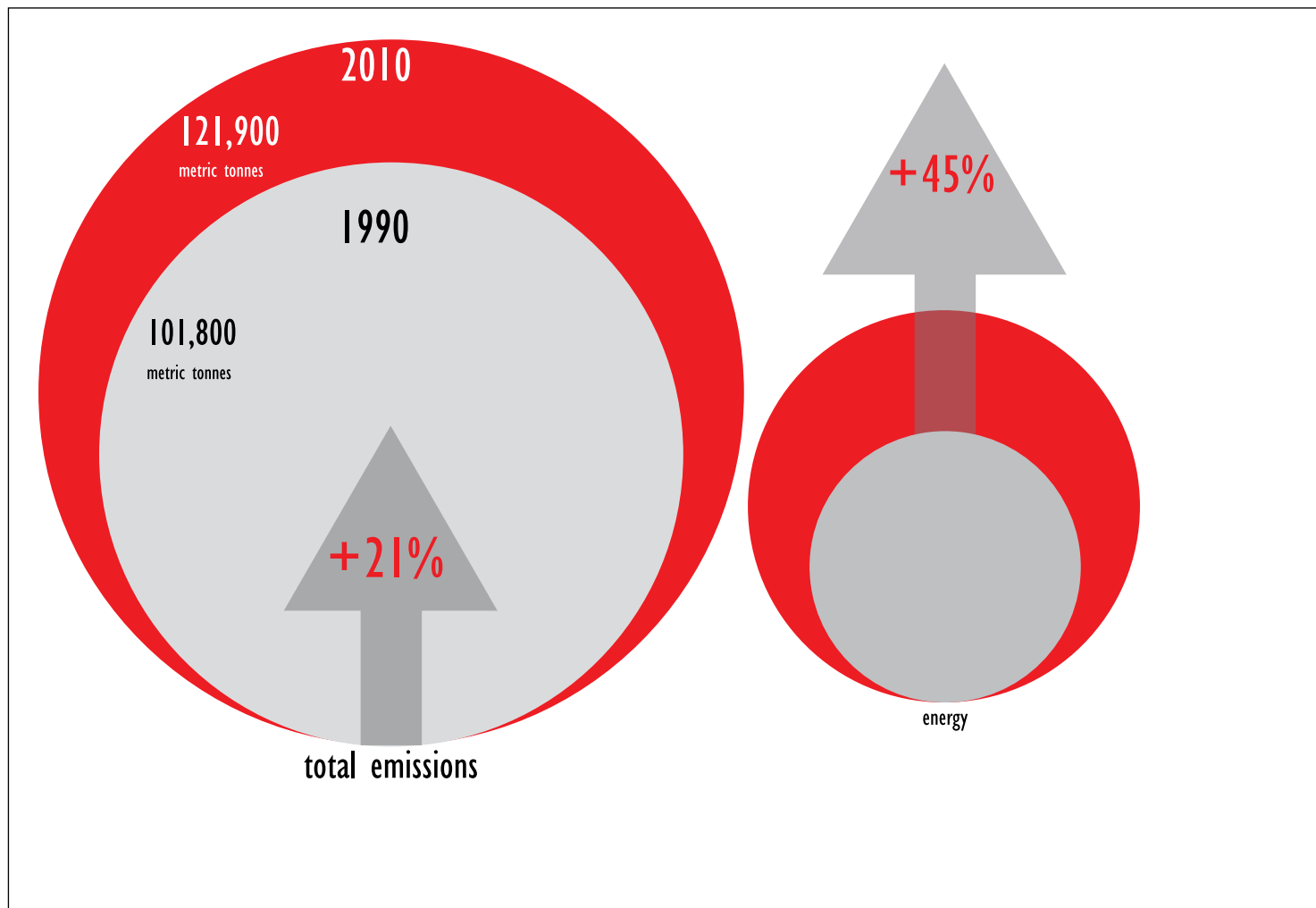
Greenhouse gas emissions, hence concentrations in the atmosphere, have increased at a greater rate from 2009 -10 than the average for previous decades. With only current policies in place the OECD estimates that “global greenhouse gas (GHG) emissions [are] projected to increase by 50%, primarily due to a 70% growth in energy-related CO₂ emissions.”²³

Not only is the trend in greenhouse gas concentrations upward, but the International Energy Agency tells us that, globally, we suffered the largest annual rise in carbon emissions ever in 2010 (Figure 2).²⁴

The OECD states that current global mitigation pledges are not enough and “more ambitious action is needed” if we are to avoid the worst impacts of climate change. The ambitious actions recommended by the OECD include stringent targets for GHG reductions, setting a price for carbon, removing subsidies for fossil fuels and supporting development of clean energy technologies.²⁵

Figure 2:
Trends in greenhouse gas emissions since 1990 (shown as CO₂ equivalent) for Victoria by sector, taken from National Greenhouse Accounts (2009/10).

Source Australian Department of Climate Change and Energy Efficiency, CfES developed infographic.

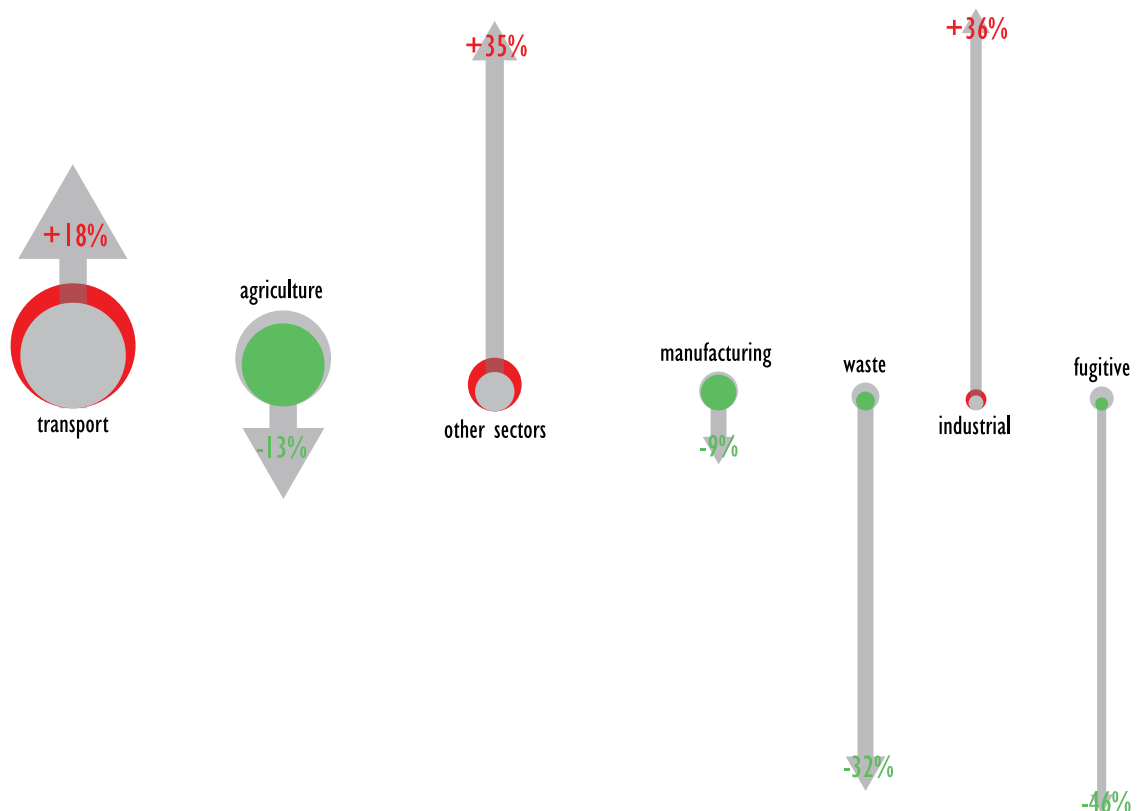


Carbon dioxide from industry, transport and energy generation has the greatest effect on global warming but other gases such as methane and nitrous oxide – anthropogenic sources of which are primarily land-management and agriculture – also make significant contributions.

Each greenhouse gas has a different warming effect on the atmosphere. The combined effect of all greenhouse gases is expressed as the amount of warming that would be caused by an equivalent amount of CO₂ - this is called CO₂e. For example, 1 tonne of methane (CH₄) is expressed as 21 tonnes of CO₂e because over the span of 100 years CH₄ will trap 21 times more heat than carbon dioxide (CO₂) while nitrous oxide (N₂O) will trap 310 times more.²⁶ This means that small amounts of some gasses have a potent effect on our climate.

Victoria's emissions profile

In Victoria, emissions - reported most recently in the Australia's National Greenhouse Accounts ²⁷ - have shown an increase since 1990 (Figure 2). Although there has been an overall increase in the period, CO₂e emissions have been largely stable since 2000 as increases from the energy and transport sectors have been approximately balanced by reduction in agricultural emissions. This is due, in part, to the fall in livestock numbers associated with the long drought.



IPCC future emissions scenarios

In an effort to promote effective planning for climate change impacts, the IPCC presents several 21st century global economic growth and development scenarios that reflect a range of possible global greenhouse gas emission levels.²⁸

These scenarios are:

A1FI: Rapid economic growth and globalisation, where energy is derived from fossil fuels

A1B: Rapid economic growth and globalisation, where energy is derived from a balanced mix of renewable and fossil fuels

A1T: Rapid economic growth and globalisation, where energy is derived from non-fossil sources

A2: Rapid Economic growth and regional development

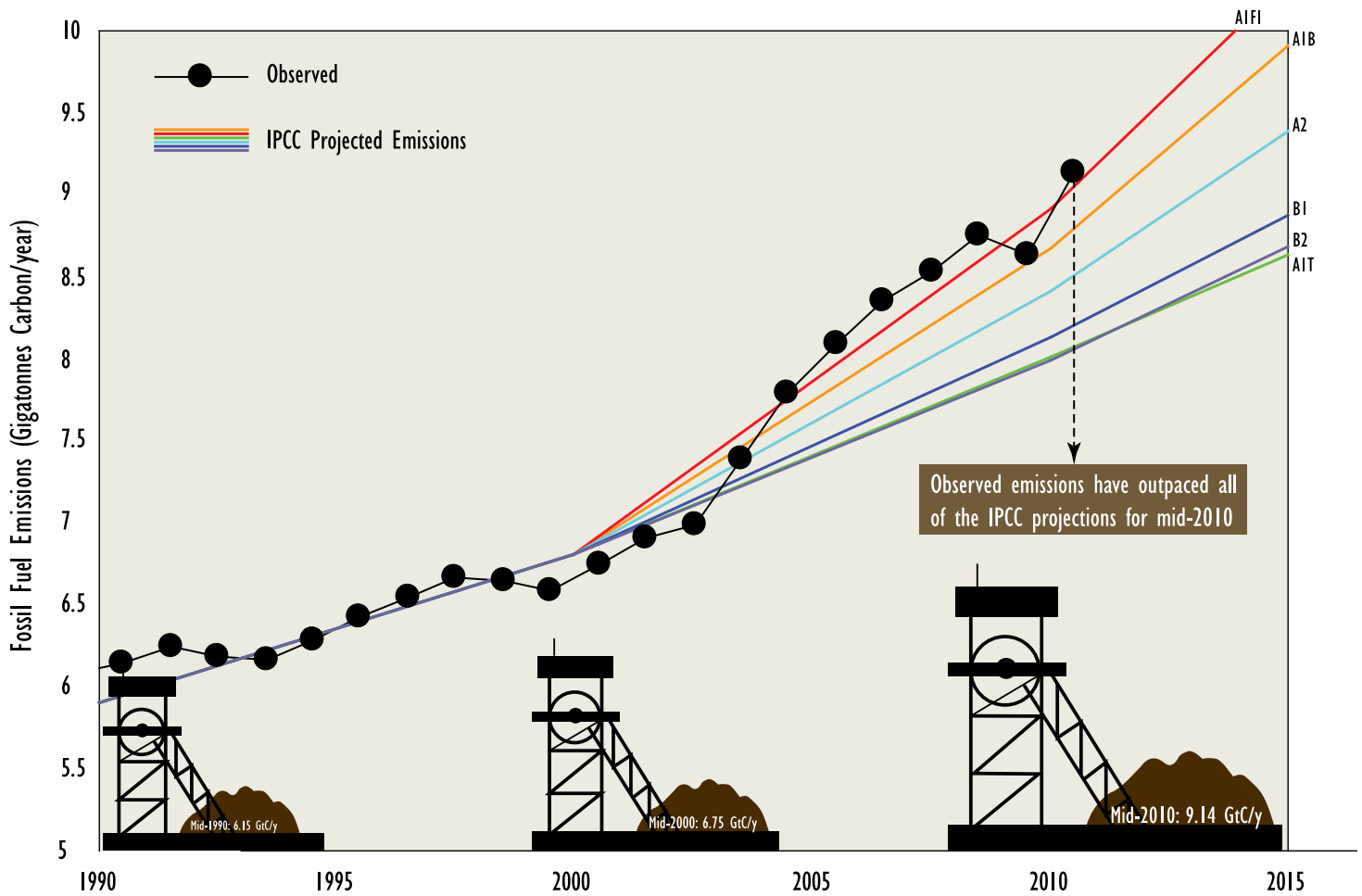
B1: Economic growth with a more environmental focus, reflecting reductions in resource use and increases in energy efficiency

B2: Sustainable development with a regional focus.

In this foundation paper, to explore climate change possibilities for Victoria, (see section 1.5) we have focussed on three of these scenarios or alternative images. The first two scenarios we use are those where rapid economic growth takes place and (a) we remain committed to the continued and unabated use of fossil fuels (A1FI) and (b) we mix our fuels (A1B). The third scenario we explore is the one where economic growth occurs with a more environmental focus and we reduce our resource use and increase our energy efficiencies. (B1).

Importantly, it needs to be noted that our global emissions are currently tracking closest to A1FI, the first and most resource intense scenario (Figure 3). This business-as-usual path represents a worst-case scenario for climate change outcomes.

However, this does not necessarily mean this is the most likely outcome because concerted global efforts to change the energy mix and consumption patterns may well alter future emissions and their impacts. In other words the global community can still arrest the emissions trajectory.



**Figure 3:
Global CO₂ emissions
from fossil fuels
compared to IPCC
projections.²⁹**

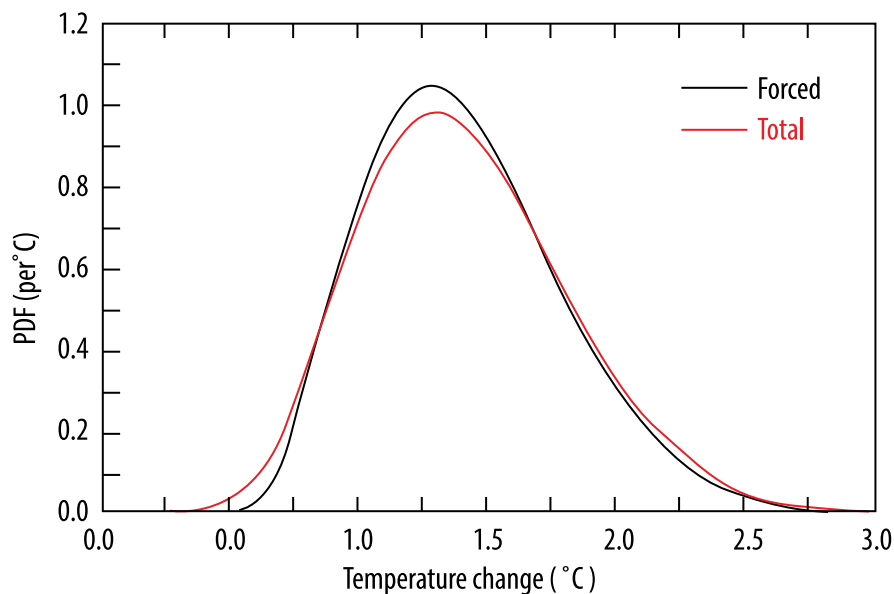
(Black dots show the annual increases in CO₂ emissions caused by burning fossil fuels. Coloured lines are the emissions expected by each IPCC scenario from 2000 onwards. Observed emissions are currently tracking at the fossil-fuel-intensive A1FI scenario. The dip in observed emissions in 2009 was caused by the Global Financial Crisis and the resulting drop in industrial activity, rather than by emissions mitigation actions.) Source CSIRO, CfES developed infographic.

1.3 Climate change risks

Rising temperatures

At present, the best CSIRO projections for Victoria suggest a 1.37°C rise by 2050 under a mixed fossil and renewable fuels scenario A1B. The range is suggested as extending from 0.91°C to 1.93°C (Figure 4).³⁰

Figure 4: Projected temperature change in central Victoria for 2050 under a mixed fossil and renewable fuels scenario (A1B), represented by Probability Density Functions (PDF) for “Forced” (greenhouse warming alone) change, and for “Total” (greenhouse warming and natural decadal variations) change. Source CSIRO.



As the plotted values increase on the Y axis, the corresponding temperature change on the X axis is more likely. The “Forced” curve shows the expected effect of greenhouse gas warming alone while the “Total” curve includes both greenhouse warming and natural variation in climate. The inclusion of natural variation leads to a slight increase in the uncertainty of outcomes. Figure 5 shows, based on IPCC data, how rising global temperatures are likely to affect us and our environment in Australia.

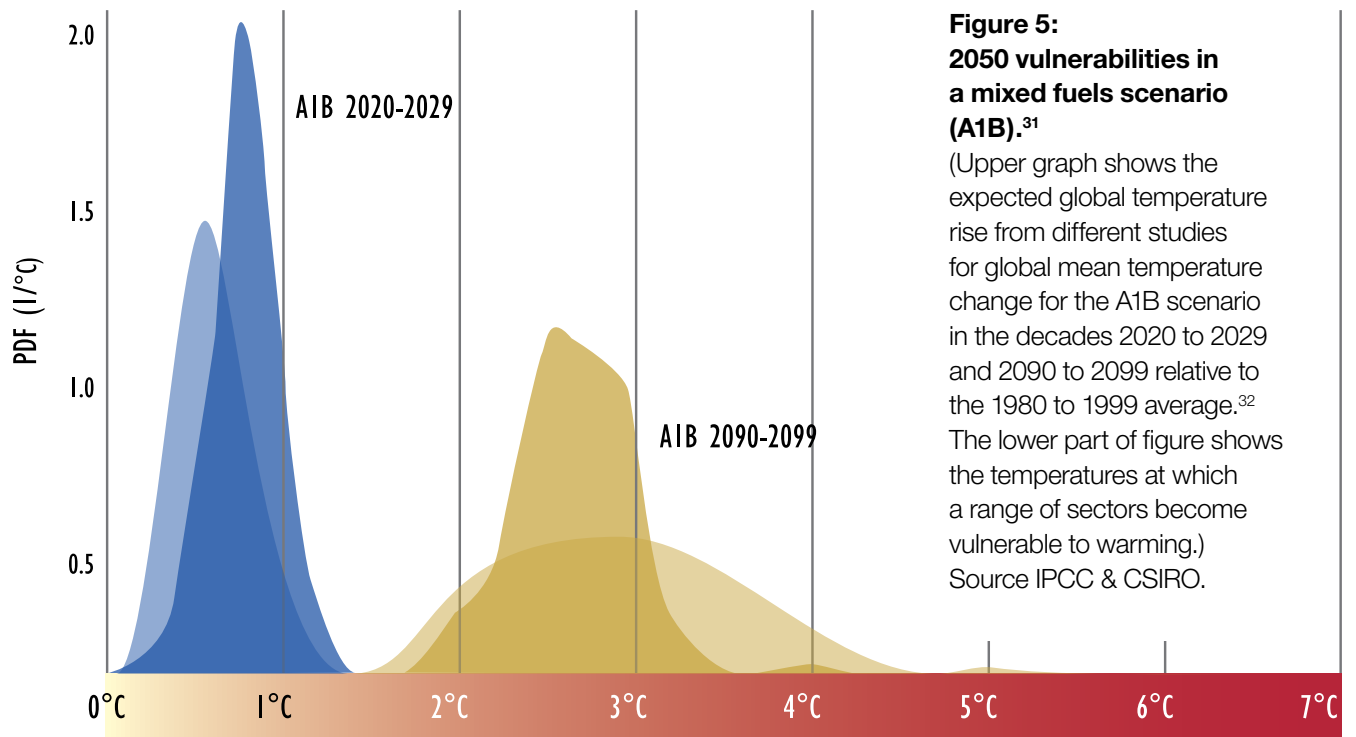
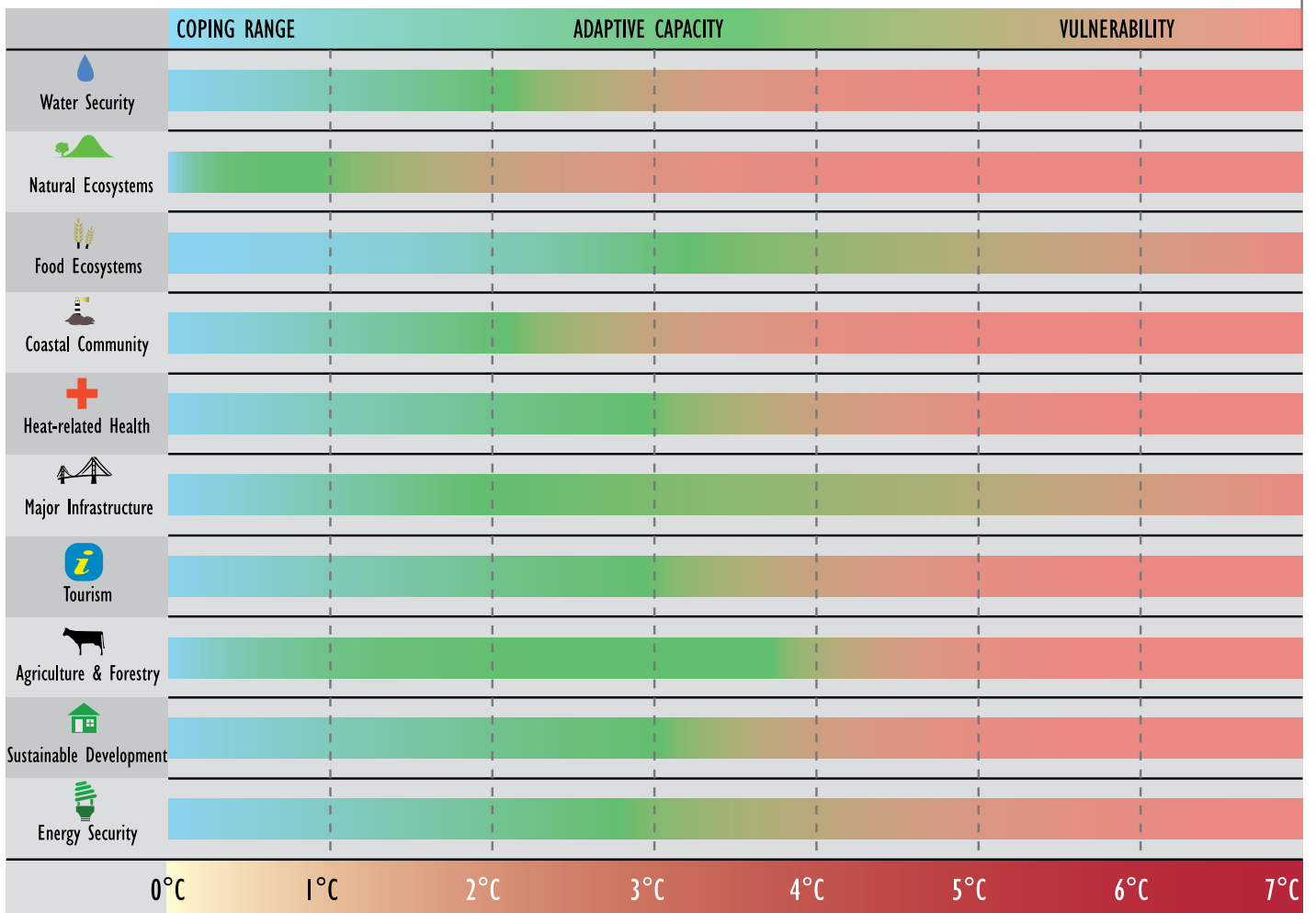


Figure 5:
2050 vulnerabilities in
a mixed fuels scenario
(A1B).³¹

(Upper graph shows the expected global temperature rise from different studies for global mean temperature change for the A1B scenario in the decades 2020 to 2029 and 2090 to 2099 relative to the 1980 to 1999 average.³² The lower part of figure shows the temperatures at which a range of sectors become vulnerable to warming.)
 Source IPCC & CSIRO.



Changes to ocean circulation patterns mean that some areas of the Tasman Sea are as much as 2°C warmer than 60 years ago.³³

1.4 Hazards and vulnerabilities for Victoria

It is apparent that projected warming for 2030 represents the upper coping limit for most ecosystems. As temperatures rise, so will environmental vulnerabilities and exposure to hazards. Risks faced will include impacts of intense storms, flash flooding and sea-level rise, loss of biodiversity and primary production, along with the migration of pest species and the increased ability of pest species to survive the warmer climate and drought impacts.

Our oceans and climate change

Long-term, slow-onset changes such as changes to the oceans around Australia will also expose vulnerabilities in natural and human systems.

Oceans are one of the primary drivers for weather and climate in Australia.

Monitoring of rising sea levels is of paramount importance for coastal communities. Changes to ocean circulation patterns mean that some areas of the Tasman Sea are as much as 2°C warmer than 60 years ago.³³ Effects of these changes in the ocean will be clearly seen in changes to marine ecosystems off our coasts. There are biodiversity hotspots of global importance that will be subject to rising temperatures at the sea surface and changing currents. Distributions of species will change as fish move southwards towards cooler waters and the impacts will be both ecological and economic.



Mushroom Reef.

Image courtesy of Parks Victoria and Museum of Victoria.

Our rainfall

In Victoria, it is expected that we will see an increase in mean temperatures. However, there is uncertainty surrounding the level of rainfall changes in our corner of Australia, but regardless of this there is still high confidence that our state will become drier as extreme events (very intense bursts of rainfall and heatwaves) will become more common.³⁴

The best estimates currently say that it is likely that Victoria will experience a decrease in mean rainfall levels. Under a mixed fossil and renewable fuels scenario (A1B), the most likely change by 2050 is a decrease in mean rainfall of 6% (although this change may be as high as 14% or as low as no change at all). When natural variability is included with human-induced changes the range of possibilities becomes larger - from a possible decrease of 17% to an increase of 5% (Figure 6).³⁵

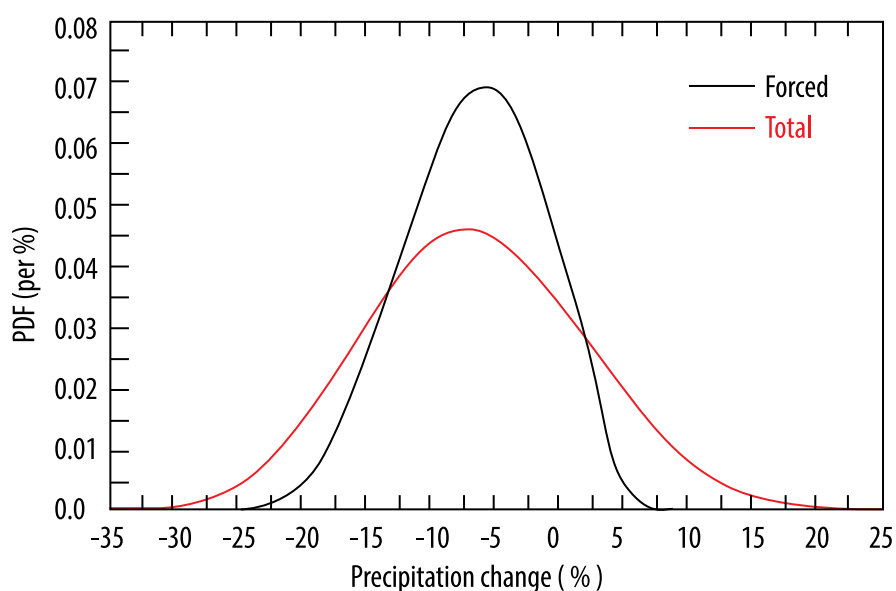


Figure 6: Projected precipitation change in central Victoria for 2050 under a mixed fossil and renewable fuels scenario (A1B), represented by Probability Density Functions (PDF) for “Forced” (greenhouse warming alone) change, and for “Total” (greenhouse warming and natural decadal variations) change. Source CSIRO.

Although there are likely to be decreases in average rainfall we are also expected to experience an increase in the intensity of the highest 1% of rainfall events. In other words, there will be more dry days but the days when it does rain will be wetter. These changes will be most pronounced in summer and autumn.³⁶ This means we will continue to have the kind of extreme rains we saw in February and March of 2011 (Figure 7) and 2012 and that events of this nature may become more severe. This possibility must be a key factor of future planning.

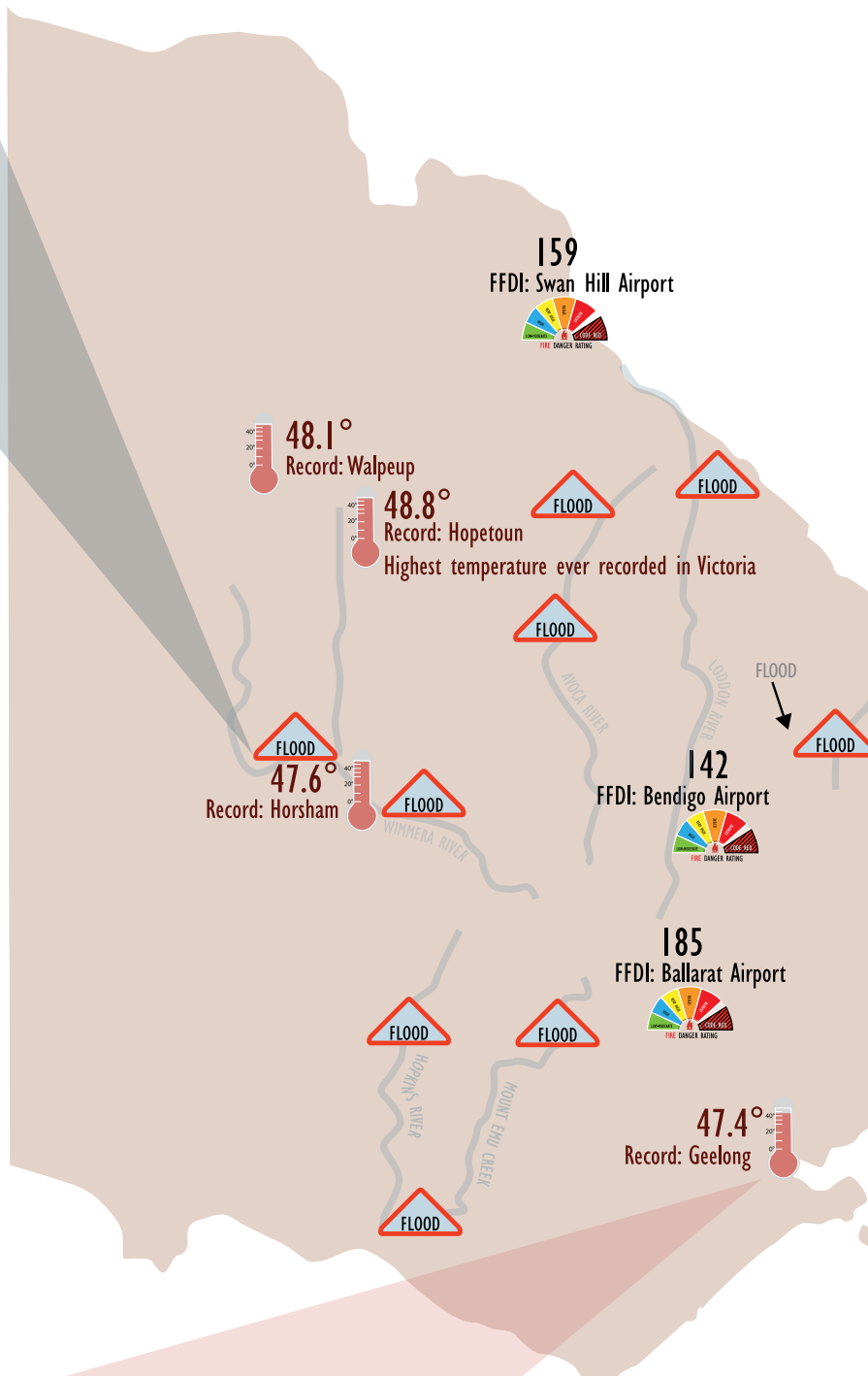
2010-11 Flooding



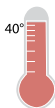
\$836M in insurance claims
123,077 hectares of grazing pasture damaged
345,645 deceased livestock (330,184 poultry)
189 public housing properties damaged
239 schools effected

Figure 7: Record-breaking Weather 2009/12.

Distribution of record breaking weather events in Victoria since 2009.³⁷
 Source Bushfires CRC, BoM, Department of Health, Vic and Comrie Flood Review, CfES developed infographic.



January-February 2009 Heatwave

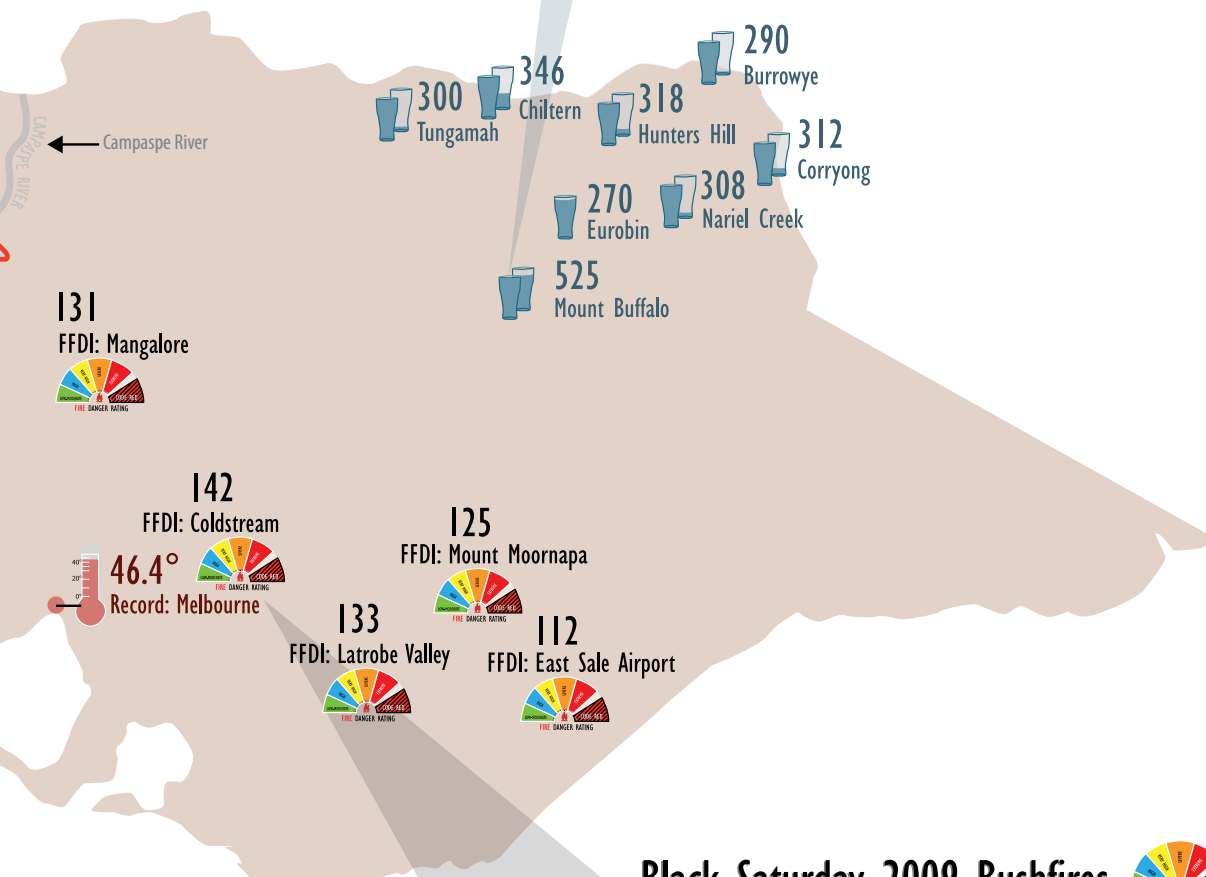


12-15° increase over normal maximum temperatures
25% increase in emergency cases (46% over the hottest 3 days)
34 fold increase in cases with direct heat-related conditions (61% of cases in people 75+)
374 excess deaths
3 days above 43°, unprecedented

- Largest riverine flood on record for this area
- Largest 7-day rainfall volume on record
- Highest temperature recorded during 2009 Heatwave
- Fire danger indices forecast for 7 February 2009

2012 Record-breaking Rainfalls

- 6+** rivers experiencing major flooding
- 130+** road closures
- #1** wettest 7-day period on record for any month
- 24** number of 7-day rainfall records broken in Victoria
- 90.25** average number of years of previous high 7-day rainfall



Black Saturday 2009 Bushfires

42.0°
Record: Wilson's Promontory

- 78** communities affected across Victoria
- 388,000** hectares burnt
- 2,298** houses destroyed
- \$926M** in economic losses (after government aid)
- 173** deaths

Explaining the Millennium Drought and 2010/11 floods

The model projections that show drier, hotter climates in Victoria may seem at odds with the cool, wet summers we saw in 2010 and 2011.

These episodes were driven by a number of factors, including the La Niña effect, and demonstrate that the weather can be highly variable on a year to year basis. La Niña is the positive phase of the El Niño Southern Oscillation. It is associated with cooler than average sea surface temperatures (SSTs) in the central and eastern tropical Pacific Ocean. La Niña is normally associated with higher than average winter, spring and early summer rainfall over much of Australia (Figure 8).

The South-Eastern Australian Climate Initiative (SEACI) researchers analysed the climate record and provide the following explanations regarding the Millennium Drought and 2010/11 floods.

*Throughout this La Niña episode the greatest rainfall anomalies in south-eastern Australia were recorded in spring (247 mm, or 60% above the 20th century average) and in the 2010/11 summer when 303 mm was recorded (150% above the 20th century average). This is the largest summer total **ever recorded** (emphasis added) by a considerable margin.*

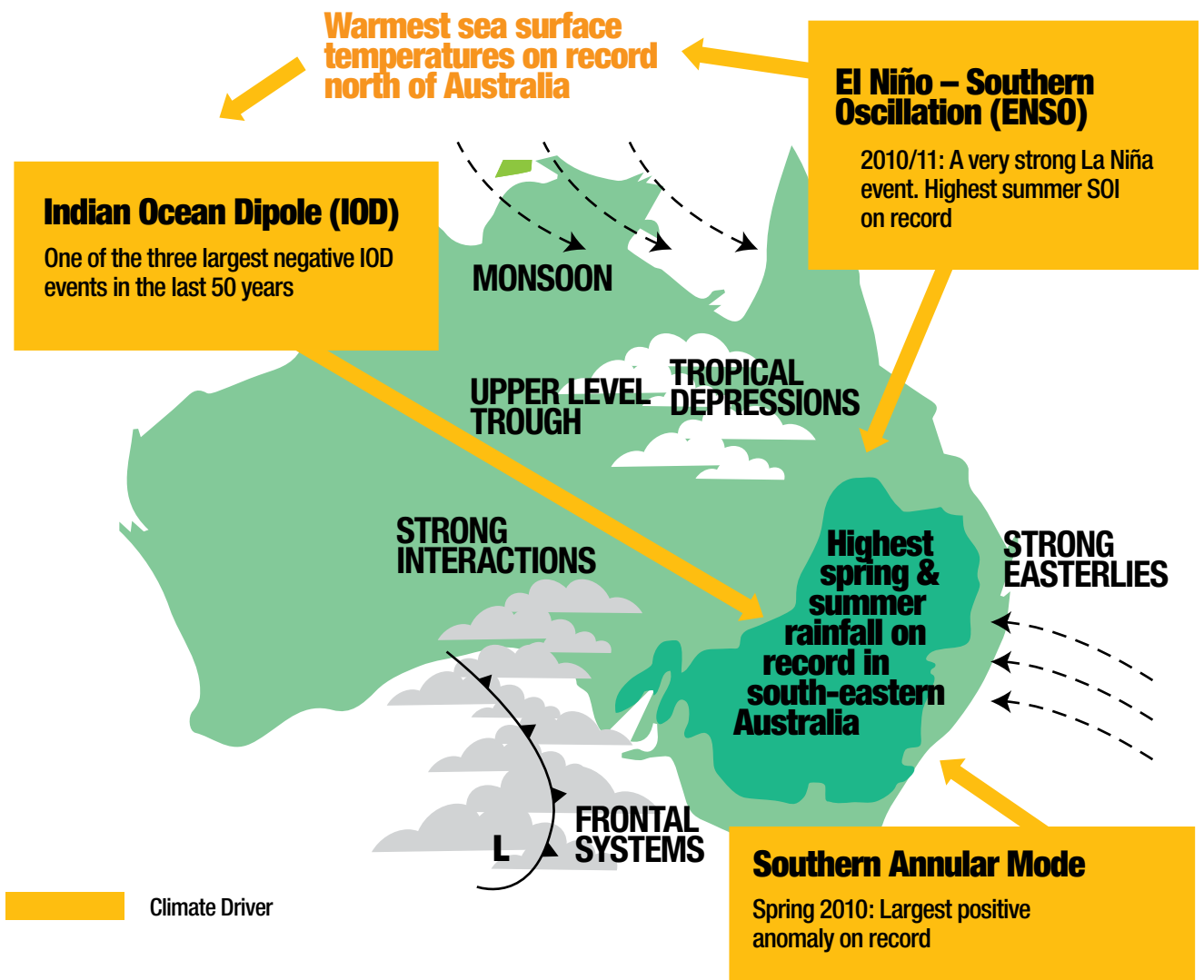
The impact of the strong La Niña was exacerbated by the Southern Annular Mode (SAM), which reached record positive values in late spring and early summer of 2010. In addition, one of the largest negative Indian Ocean Dipole (IOD) events of the last 50 years was recorded in 2010.

SEACI researchers have analysed the observed climate record and found that the El Niño – Southern Oscillation and other large-scale modes of variability cannot explain the observed decline in autumn and early-winter rainfall in south-eastern Australia.

SEACI researchers have, however, found a strong relationship between the rainfall decline in south-eastern Australia and the intensity of the subtropical ridge (STR), with the decrease in rainfall strongly associated with increasing surface pressure in the latitudes of the STR. The strengthening of the STR is estimated to account for around 80% of the recent rainfall decline in south-eastern Australia.

Research indicates that there are changes in the Hadley Cell (and hence changes in the STR) associated with global warming. In particular, the STR has intensified with increasing global surface temperature. This result implies that the rainfall decline in south-eastern Australia may have some link to global warming. To investigate this, SEACI researchers conducted simulations of the global climate over recent decades using a global climate model and different external forcings (natural and anthropogenic). In these simulations, the climate model was only able to reproduce STR increases and other modifications of the Hadley Cell when anthropogenic forcings (e.g. greenhouse gases) were present in the simulation along with the natural forcings.

This gives confidence that there is a link between the rainfall decline across south-eastern Australia and increasing greenhouse gas concentrations in the atmosphere.³⁸



Australia can continue to expect cool, wet years and whilst there may not yet be a full understanding of how climate change will affect these processes, the evidence indicates that it does.⁴⁰ There is confidence that these cool, wet years will occur in a context of a long-term climate that is both hotter and drier and we should not expect periodic, short-term wet years to recharge dry landscapes.⁴¹

Figure 8:
In 2010/11 south-eastern Australia recorded record-breaking rainfall in spring and summer due to the combination of the positive phase of all large-scale modes of variability known to contribute to the year-to-year variability of rainfall: ENSO, IOD and SAM.

Source SEACI.

Modified by CfES.³⁹

Overall, short-term projections indicate that there will be increases in acute hazards, while in the long-term, changes in baseline conditions will mean that vulnerable systems will need to adapt or risk being overwhelmed.

An increase in extreme events....

In Victoria, we are experiencing extreme events such as heatwaves, storms, drought and bushfire more often. These events are immediate and easily observed and raise questions about whether they are the result of climate change and how global climate change will affect our lives.

An increase in these events is consistent with a warming planet but, as already noted, linking individual events to climate change is problematic as this requires long-term climatic data sets of 30 years or more. Some analyses of this nature have been carried out in the UK and concluded it was “very likely that global anthropogenic greenhouse gas emissions substantially increased the risk of flood occurrence”.⁴² Such studies are rare, but are likely to become less so.

The increasing frequency of these events led the IPCC to produce a special report in 2011 that brought together the best scientific projections on changes in extreme weather at a global scale.⁴³

The IPCC concluded that:

- It is “virtually certain (99-100% probability)” that heat extremes will increase and cool extremes will decrease.
- It is “very likely (90-100% probability)” that heat waves will increase over most land areas and extreme high water levels will occur with sea level rise.
- It is “likely (66-100% probability)” that increases in rainfall will occur over some land areas (medium confidence that they may also accompany a mean rainfall decrease in some areas), and tropical cyclone mean wind speed will increase but numbers of actual events will remain unchanged or decrease.

Overall, short-term projections indicate that there will be increases in acute hazards, while in the long-term, changes in baseline conditions will mean that vulnerable systems will need to adapt or risk being overwhelmed (Figure 9).

The economic strain

The effects of more frequent extreme weather events have been recognised as an issue by the financial industry, particularly the insurance sector. The sector recognises that mechanisms must be developed to manage and compensate for the consequences of these events. Insurance provides a key method for businesses and individuals to manage financial risk.

Economic losses amounted to some US\$ 380bn in 2011 making it the most expensive natural disaster year to date, multiples more than the previous record (US\$ 220bn) set in 2005. At US\$ 105bn, insured losses also were at new high. The loss figures were dominated by 2011's earthquakes – in addition to Japan, above all the devastating event in New Zealand. However the year also saw the floods in Australia, Thailand, France and Italy and the tornado outbreak in the USA.

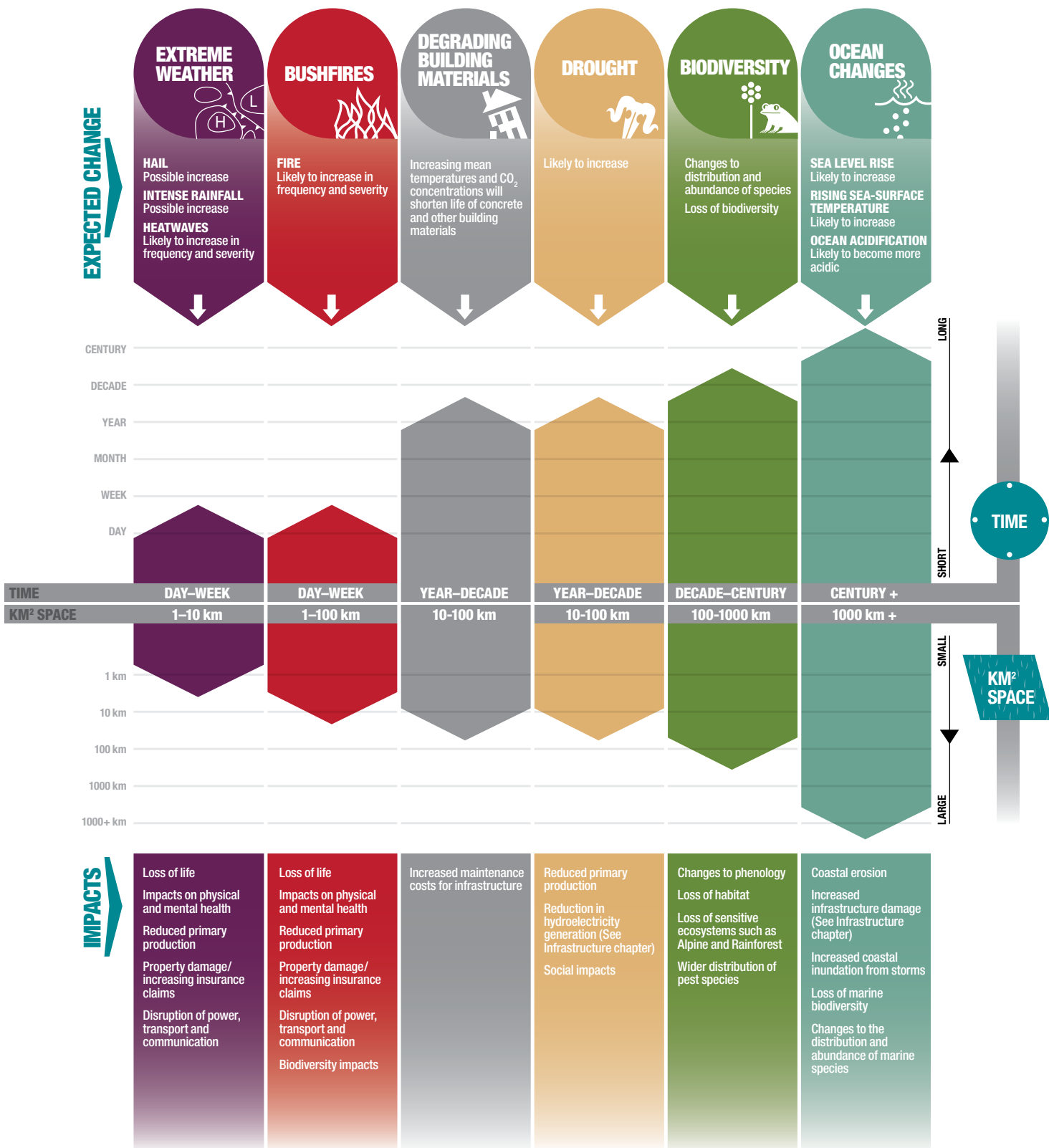
The reinsurer, Munich Re, in reporting these figures states that weather-related risks in the USA and Canada are constantly changing as a result of anthropogenic climate change and natural climate cycles like La Niña.⁴⁴

Munich Re was considering the potential impact of climate change on business as early as the 1970's.

Economic losses amounted to some US\$ 380bn in 2011 making it the most expensive natural disaster year to date...

Figure 9:
Scale and onset time
of climate change
hazards in Victoria.

Source IPCC, CSIRO
 CfES developed infographic.



1.5 Our climate types

Köppen's scheme to classify world climates was devised in 1918 by Dr Wladimir Köppen of the University of Graz in Austria⁴⁵ and has achieved wide acceptance amongst climatologists. In 2000, the Australian Bureau of Meteorology produced a modification of the Köppen climate classification system,⁴⁶ to better address the relationship between climatic subdivisions, features of the natural landscape and the human experience of climate, and applied the modification to Australia.

Pursuant to the classification system, the climate types that typify south-east Australia (Victoria) are:

Subtropical: Moist climate that can be cool or warm.

Subclasses:

- No dry season
- Moderately dry winter

Temperate: Lower temperatures and higher rainfall than Grassland.

Subclasses:

- No dry season (hot summer)
- Moderately dry winter (hot summer)
- Distinctly dry (and hot) summer
- No dry season (warm summer)
- Distinctly dry (and warm) summer
- No dry season (mild summer)
- Distinctly dry (and mild) summer
- No dry season (cool summer)

Grassland: Dry climate with warm to hot temperatures.

Subclasses:

- Hot (persistently dry)
- Warm (persistently dry)

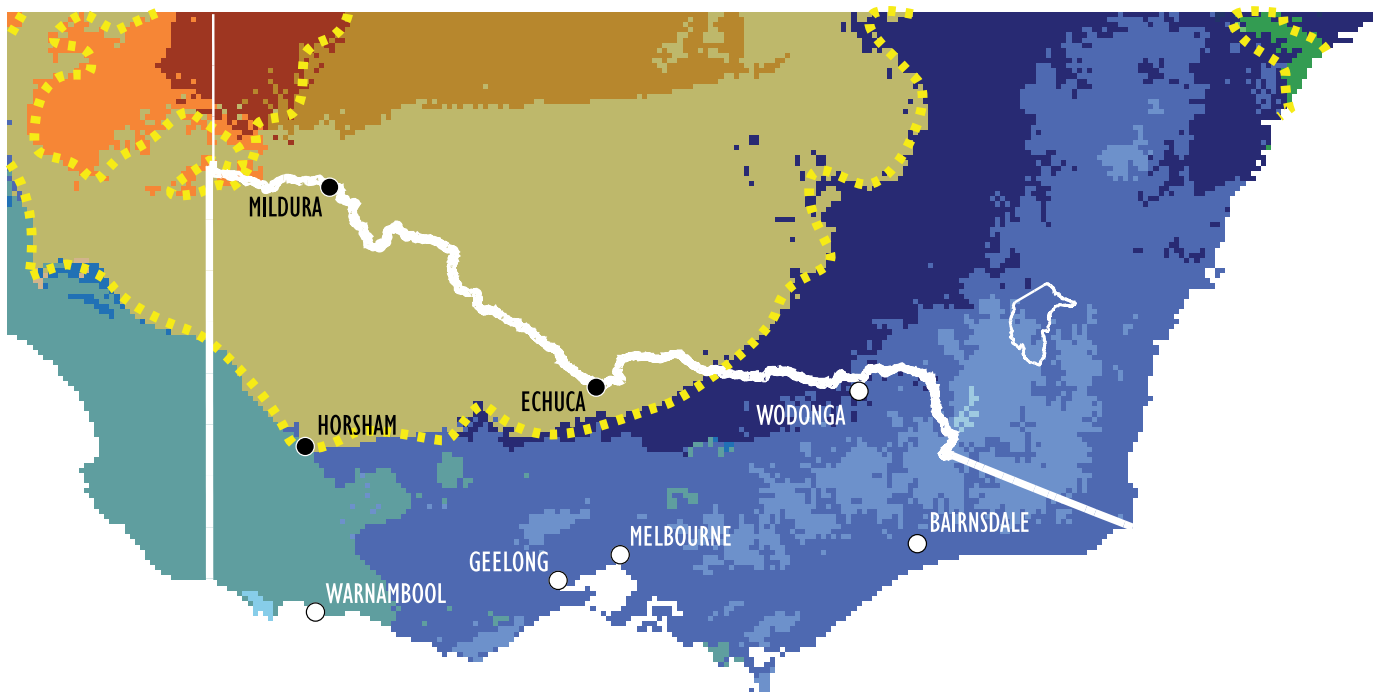
Desert: High temperatures; persistently dry - typical of much of the interior of Australia.

Subclasses:

- Hot (persistently dry)
- Warm (persistently dry)

When mapped for the 30-year period between 1975 and 2004 (Figure 10) the data show that Victoria is dominated by two broad climate types: **Grassland** in the northern plains and **Temperate** in the southern and mountain areas. Our state borders on the **Desert** climate type in the northwest, close to Mildura.

Baseline Climate: 1975-2004



TEMPERATE

- * TE no dry season (hot summer)
- * TE moderately dry winter (hot summer)
- * TE distinctly dry winter (hot summer)
- * TE distinctly dry (and hot) summer
- * TE no dry season (warm summer)
- * TE moderately dry winter (warm summer)
- * TE distinctly dry winter (warm summer)
- * TE distinctly dry (and warm) summer
- * TE no dry season (mild summer)
- * TE moderately dry winter (mild summer)
- * TE distinctly dry (and mild) summer
- * TE no dry season (cool summer)



GRASSLAND

- * GR hot (persistently dry)
- * GR hot (summer drought)
- * GR hot (winter drought)
- * GR warm (persistently dry)
- * GR warm (summer drought)
- * GR warm (winter drought)



SUBTROPICAL

- * ST no dry season
- * ST distinctly dry summer
- * ST distinctly dry winter
- * ST moderately dry winter



DESERT

- * DE hot (persistently dry)
- * DE hot (winter drought)
- * DE warm (persistently dry)

Boundary between broad climate classes

* Climate class appears on map

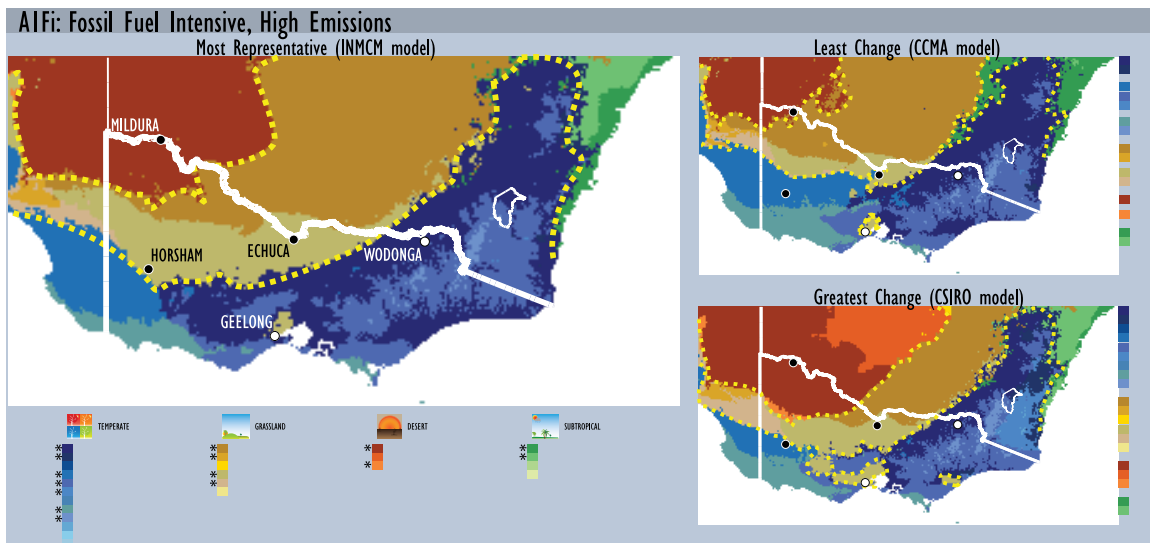
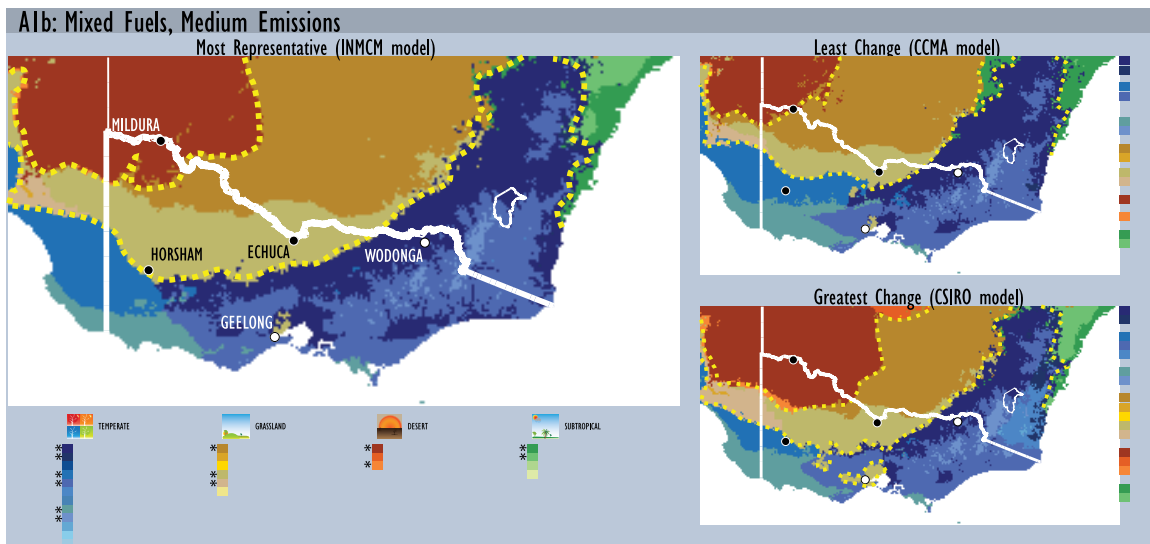
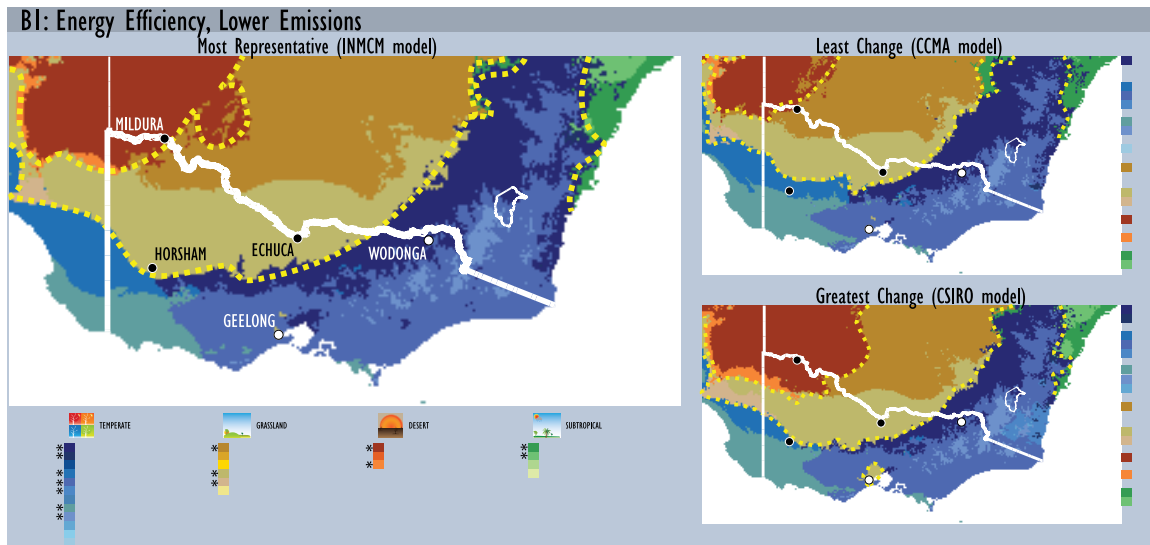


Figure 10: Modified Köppen climate classification for southeastern Australia for the period 1975-2004 compared to modelled outcomes for the year 2050 under IPCC scenarios A1FI, A1b and B2. Source BoM, CSIRO, CfES developed infographic.

Future Climate in Victoria

At our request CSIRO has provided us with Victorian climate change data from the output of 23 global climate models. Use of these 23 models - which projected the outcomes of 3 IPCC scenarios (A1FI, A1B and B1) and set them within the context of the modified Koppen climate classification - allows us to examine, compare and contrast potential ranges of climate change outcomes in Victoria.

Climate models are complex computer simulations founded on the basic laws of physics, chemistry and fluid motion and they have been used for weather forecasting, understanding climate and determining climate change possibilities. The first climate model was developed in 1969 by Drs Syukuro Manabe and Kirk Bryan. In 1975 Drs Manabe and Richard T Wetherald first applied modelling to simulate climate change.⁴⁷

Each of the models developed by climate scientists represents potential future climate processes a little differently depending on assumptions. These differences do not indicate disagreement between researchers but rather reflect uncertainties in how best to represent complex processes.

We tracked the modelled results for Victoria and mapped the outcomes across the state for 2050 (Figure 10).

The Australian Bureau of Meteorology's modified climate classification system has been applied to the data, in order to determine how the output of the various models is reflected in the range of possible future climate classes in the state.⁴⁸

This work has not been undertaken before.

Consideration of the results from an examination of each of the 23 models illustrates a best assessment of the possible variations in climate associated with climate change scenarios.

Projections show a range of magnitude in changes, but most of them indicate a southward movement of the Temperate and Grassland climate and movement of Desert climate into the northwest of the state. This movement reflects rising temperatures and a general decrease in rainfall in most of the 23 models.

In the material which follows we present a mid-range case that is most representative of the range of outcomes. We also present the cases that show the most and the least possible change.

Change in Victoria over time according to the three scenarios

The range of modelled results indicate that, if global greenhouse gas emissions continue on their present path, the shifts in climate type in a given region may vary in magnitude. This range of possible outcomes is mainly driven by uncertainties in the response of rainfall patterns to global warming. Whilst all the models agree that temperatures will rise, there is greater uncertainty in the response of rainfall patterns.

The majority of outcomes show less rainfall across the state.

Taking all the model projections and summarising them for south-east Australia, we find that by 2050 the projection is for a substantial decrease in the *Temperate* climate area and this is matched by an increase in *Desert* climate (Figure 11).

A relatively small change is anticipated in the extent of broad *Grassland* climate, but there is a shift from the warm subclass to the hot subclass in the area under study. This demonstrates a rise in mean temperatures.

An increase in the extent of *Subtropical* climate is projected as this zone is expected to move southward. New South Wales mainly feels this impact, but the projected movement may be of importance in Victoria in the second half of the 20th century as climate zones continue to move southward.

The ecosystem impacts of these changes will be complex but are likely to include: reduced snow cover, changes in fire dynamics, more invasive species and changes in ranges of species currently present in Victoria, either southwards or to higher altitudes.⁴⁹ It is expected that many vulnerable species will experience contractions of their current ranges.⁵⁰

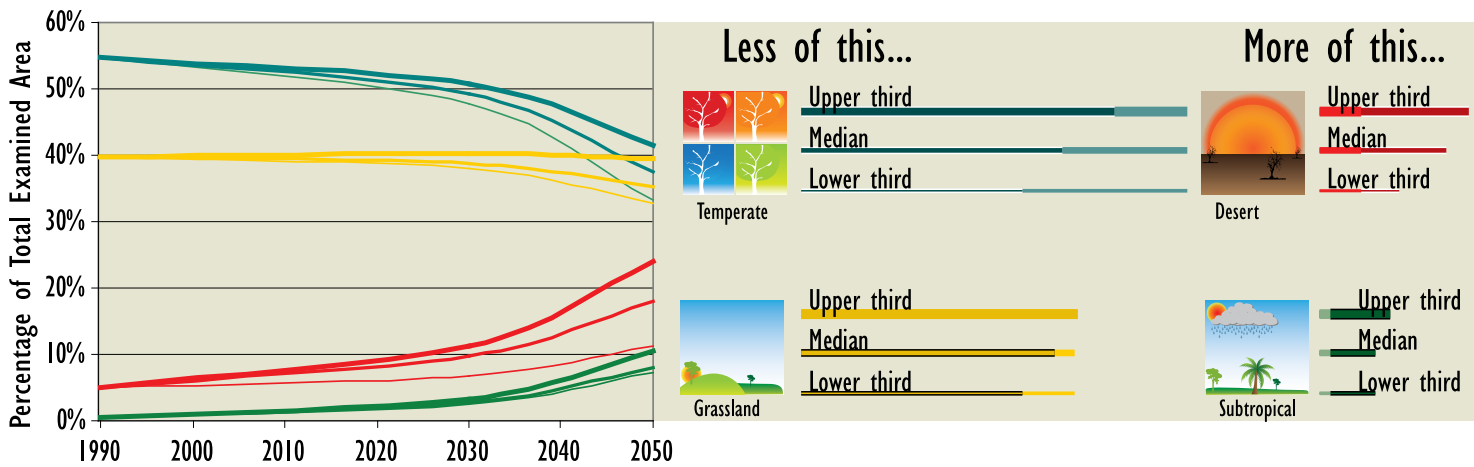


Figure 11: Projected change in area covered by *Subtropical*, *Temperate*, *Grassland* and *Desert* climates in SE Australia in 2030 and 2050 compared to 1990 under an unabated use of fossil fuels scenario (A1FI). The plots summarise the output of 23 global climate change models and show the median change across all models and the range of the middle 33% of changes. Source BoM, CfES developed infographic.

We will also see the emergence of a dry *Grassland* zone to the west of Melbourne and an increasingly hot climate over Melbourne itself.

Temperatures will rise, rainfall will decrease

From the perspective of Victorian settlements, there are several striking outcomes present in these modelling projections for south-eastern Australia.

Among these are the southward movement of a *Desert* climate into the Mallee. We will also see the emergence of a dry *Grassland* zone to the west of Melbourne and an increasingly hot climate over Melbourne itself. We examined these areas in more detail by analysing the possible changes in three communities: *Mildura*, *Avalon* and *Melbourne CBD* (Figure 12).

Mildura

At present, Mildura sits in a *Warm Grassland* climate. As temperatures rise, most models show movement of hot-dry climate types into the northwest of Victoria by 2050. Under the A1FI scenario, 57% of models show *Hot Desert* climate over Mildura, while the rest show *Hot Grassland*. Under the A1B scenario, the proportion of models showing *Hot Desert* climate over Mildura falls slightly to 52% and under the B1 scenario, only five models show this outcome. Even under the B1 scenario, all models show a change from the climate currently experienced.

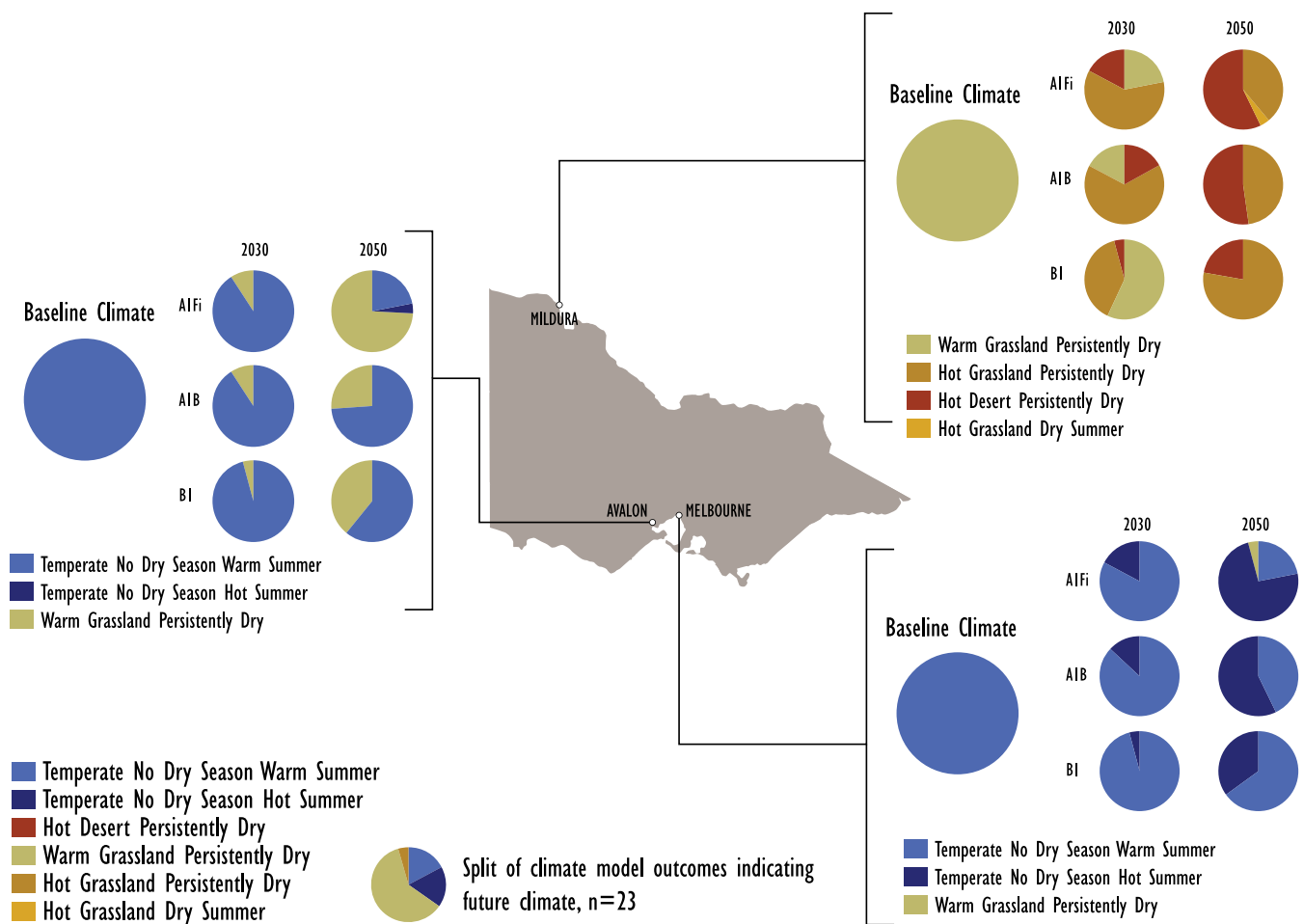
Avalon

Avalon lies to the west of Melbourne in an area of the state that is particularly dry. As mean global temperatures increase, this dryness will become more pronounced and, in the consensus model (A1FI), the area around Avalon shows a shift from the present *Temperate* climate, to a drier *Warm Grassland*. Figure 11 shows how the scenarios influence this transition. By 2050, under the A1FI scenario, the *Warm Grassland*, *Persistently Dry* climate class is the most likely outcome (found in 17 of 23 models).

Melbourne CBD

Melbourne's CBD has an observable urban heat island effect, wherein the expanse of urban infrastructure acts to raise temperatures several degrees above the surrounding area. In the next 40 years, the model outputs suggest that this effect will act to create a climate class around the city that is observably warmer. This can be seen in the mid-case map for the A1B scenario (Figure 12) where Melbourne has a *Temperate Hot Summer* class, compared to *Temperate Warm Summer* class in the surrounding areas.

Comparison of the model outputs indicates that, under the A1FI scenario, *Temperate Hot Summer* is the most likely outcome (found in 17 of 23 models) and transition to *Grassland* class is also a possibility by 2050.



The discussion of the 23 models and projections presents a number of possible climate change outcomes in Australia. The differences in outcomes according to the SE Australia scenarios provide us with a powerful reminder of the importance of immediate and committed action to limit global greenhouse gas emissions.

Figure 12:
Climate trends in 2050 for Mildura, Avalon and Melbourne CBD based on the 23 global climate models for the IPCC emissions scenarios A1FI, A1B and B1.

Source BoM, CfES developed infographic.

This work reinforces our research. In a warming world, warmer and drier Australian climates will migrate southward.

Analogue Township Model

The threat of a global mean temperature rise of 4°C has also been examined in detail by CSIRO. Scientists have concluded that if there were a rise of 4°C globally, we could expect increases of 3 to 5°C in coastal areas and 4 to 6°C inland. Decline in rainfall would be likely in southern Australia, especially in winter. Near complete loss of snow cover could be expected in alpine regions.⁵¹

To provide an appreciation of the potential for change in highly localised terms, CSIRO has developed an ‘analogue township’ model. This approach examines the projected future climate conditions for selected towns and cities and finds locations in Australia where such conditions already exist.

Research like this gives us a complementary view to the changing climate classifications shown earlier. Where the climate classification maps show us how climate zones will migrate southwards, this work presents possible changes as if the climate remained stationary and towns moved northwards. Using this method, we can look to other communities for guidance on how best to adapt to future climates.

There are a range of possible futures with a global 4°C temperature rise, due to different model results. Analogue towns have been identified for several such outcomes.

With a small rise in temperature and increase in rainfall, Melbourne is expected to have a climate similar to the one we currently see in Wyalong, NSW. Under the hottest, driest outcome, Melbourne should expect to experience the climate of Leeton NSW.

The full range of analogue township expected future climates is shown in Figure 13 where we have represented Melbourne and Nhill.

This work reinforces our research. In a warming world, warmer and drier Australian climates will migrate southward.

Victorian communities will need to consider strategies to deal with this change across a broad range of lifestyles and sectors. Innovation is likely to be a key factor for our continued wellbeing and prosperity.

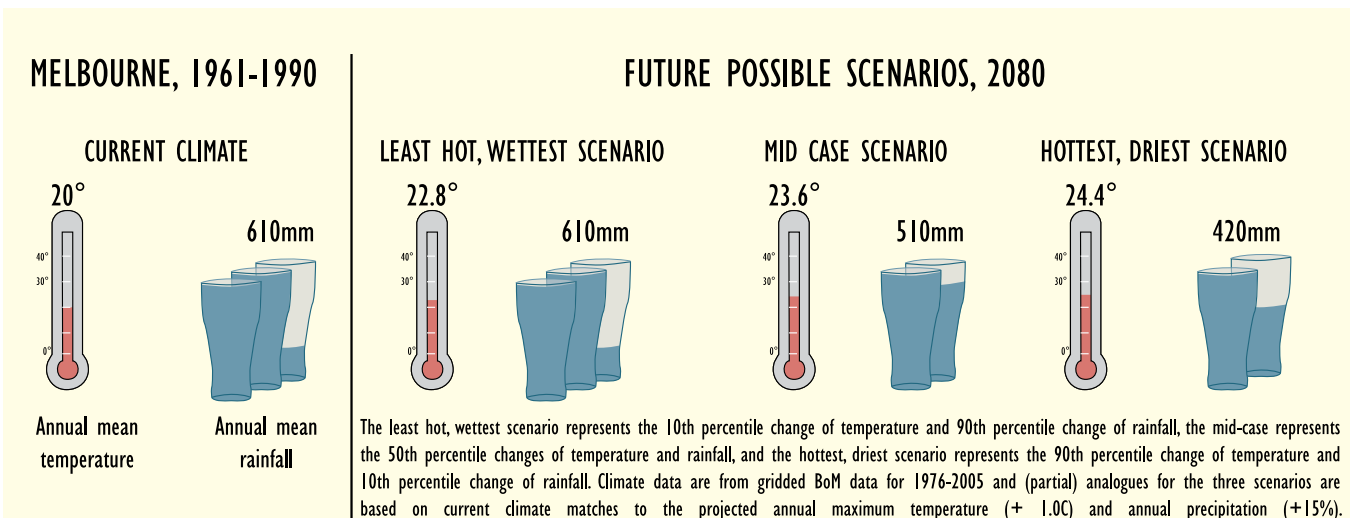
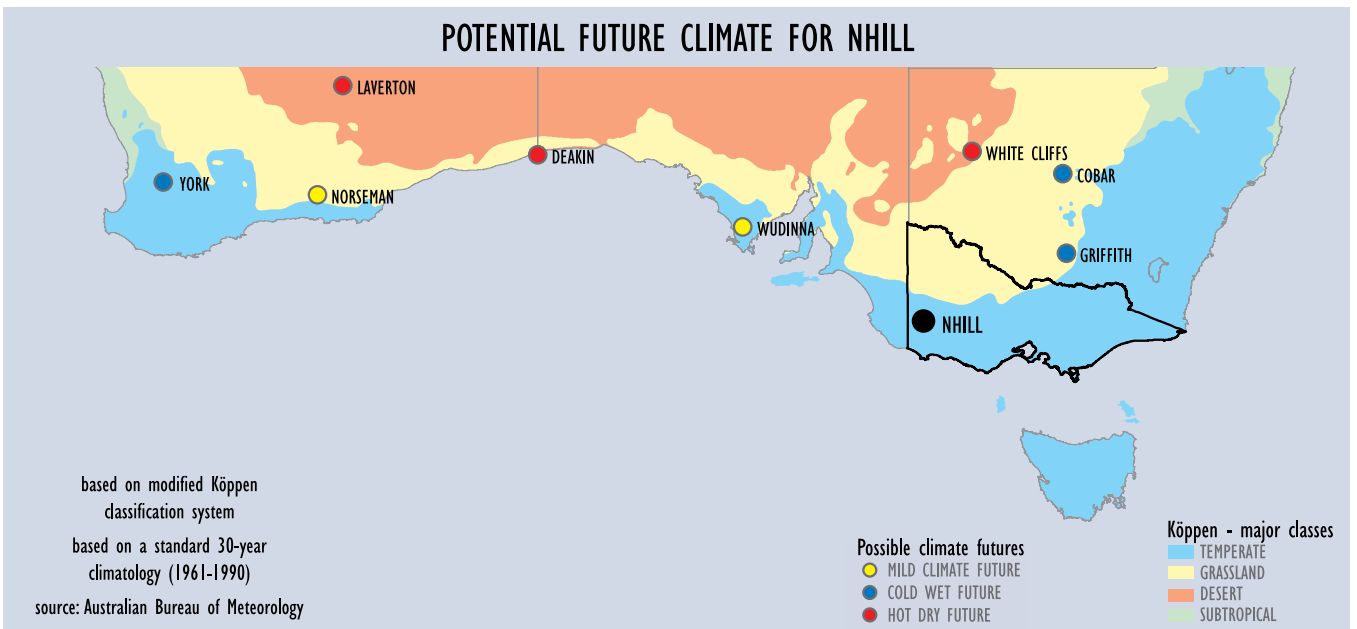
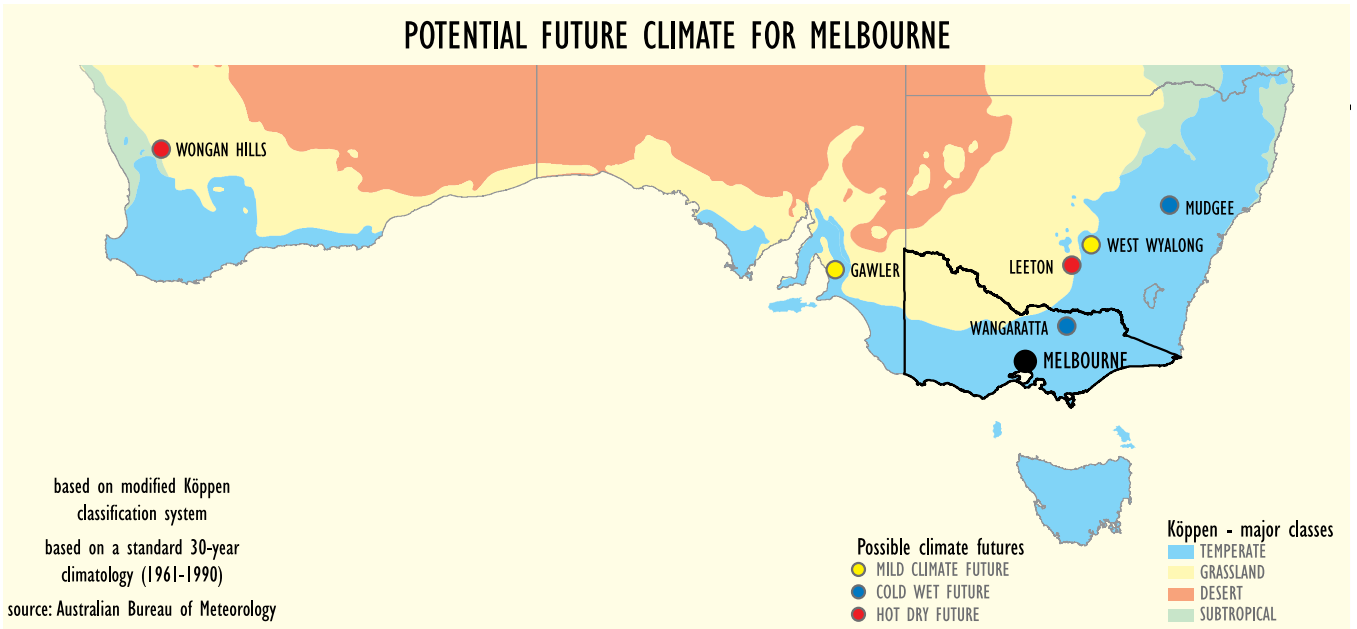


Figure 13:
Possible climates for Melbourne and Nhill in 2080 – assuming an increase of 4°C of mean global warming.
Red indicates the hottest, driest scenario' yellow the mid-range scenario and; blue the least hot, wettest scenario.
Source CSIRO.

CHAPTER TWO - BIODIVERSITY AND CLIMATE CHANGE

Climate change is predicted to compound existing pressures on Victoria’s biodiversity and ecosystems.⁵³

This chapter discusses the impacts of climate change on Victoria’s biodiversity and primary production. Pressures other than climate change (and management responses) will be discussed in the upcoming *Biodiversity and Land Foundation Paper*. The impacts of drought and flood on primary production are discussed in Chapter Four.

Biodiversity is critically important to our wellbeing.

‘There is an increasing recognition that protecting other species is a smart strategy for the long-term benefit of humans ... our crops, domestic animals, pharmaceuticals and other chemicals, building materials, fuels and many other products ... come from other species, ecosystems and biodiversity ... regulate the atmosphere, maintain soil fertility, promote food production, regulate water flows, control pests and manage waste disposal.’⁵²

Climate change is predicted to compound existing pressures on Victoria’s biodiversity and ecosystems.⁵³ The capacity of natural ecosystems to adapt to climate change will be improved if existing threats are addressed.

Projections of significant shifts in local climates, and increases in disturbances such as bushfires and storms, will impact on Victoria’s natural ecosystems and primary production industries alike. Impacts will not be limited to Victoria’s terrestrial environments, with ocean warming, acidification and sea level rise predicted to impact on marine ecosystems.



Strathbogie butterflies.

CfES image.

2.1 Biodiversity and ecosystem health

Australia's unique and 'megadiverse'^v natural environments are already responding to climate change.

Species are moving to higher elevations in alpine regions, some species' ranges are expanding southward to cooler climates, migratory birds are arriving earlier and departing later, mating seasons are occurring earlier, and coral bleaching appears to be occurring at elevated rates.

These responses not only indicate that climate change is already affecting biodiversity, but that this is occurring significantly faster than expected and with modest temperature change (< 1°C) when compared with projections.⁵⁴

A warming of 1 to 1.5°C is already understood to put natural ecosystems at risk, and increase the likelihood of extinction of species vulnerable to climate change. A rise of over 2°C is likely to greatly accelerate extinctions and wide-scale changes to natural ecosystems.⁵⁵

Although most Victorian species appear able to withstand short-term climatic variability, longer-term shifts in climate and the increased frequency or intensity of extreme events will provide a significant challenge to the survival of many species because of their limited capacity to adapt to changing environments.

If the adaptive capacity of species is exceeded, migration to more suitable conditions will be a necessity. A compounding factor in Victoria is that the high level of habitat fragmentation will limit the migration opportunities of the less-mobile species. Species inhabiting high-altitude or southerly habitats will have limited scope to migrate.

A warming of 1 to 1.5°C is already understood to put natural ecosystems at risk, and increase the likelihood of extinction of species vulnerable to climate change. A rise of over 2°C is likely to greatly accelerate extinctions and wide-scale changes to natural ecosystems.⁵⁵

v 7-10% of all species on earth occur in Australia.

For areas exposed to severe climate shifts, it is possible that significant localised extinctions will occur.

Pest plants and animals will also change their distribution in response to climate change, increasing competitive pressures on native species.

Climate change impacts will vary from ecosystem to ecosystem - some will be less resilient than others. Ecosystems such as rainforest, wetlands, alpine areas and coastal and marine habitats have been identified as being at greatest risk in Victoria. Impacts will also differ between terrestrial, freshwater, and coastal and marine environments because the main drivers of change will vary.

What makes a species vulnerable to climate change?

Victorian flora and fauna species with the following characteristics are believed to be highly vulnerable to climate change:⁵⁶

- Restricted in geographical and climatic range;
- Small population sizes or limited to small and/or isolated areas of habitat;
- Reliant on continuous habitat for migration and dispersal;
- Sensitive to changes in competition;
- Reliant on ecosystems that are already stressed by other impacts such as clearing;
- Reliance on complex interactions with other species for reproduction, dispersal or growth;
- Reliance on 'narrow' food source;
- Reliance on critical environmental cues for migration and breeding;
- Low levels of genetic variability;
- Low reproductive output; and
- Poor dispersal capacity.



Spotted Tree Frog.

Image courtesy of Glen Johnson.



Red-tailed Black Cockatoo.

*Image courtesy of Wayne Bigg.
<http://www.redtail.com.au>*



Mountain Pygmy-possum.

Image courtesy of Fredy Mercay.

Primary Production and Carbon Storage

In addition to impacts on natural ecosystems, climate change also threatens agriculture, forestry and fisheries through impacts on water resources, land health, agricultural yields, increased damage from wildfires and storms, and changes to the distribution and abundance of commercial species.

Future land-use patterns and the location of primary industries in Victoria may have to alter in order to adapt to climate change. Changes to the distribution of primary production will have socio-economic implications for individual businesses, industries, towns, schools and regions.

Climate change related ecosystem changes will influence the amount of carbon storage in the natural environment, having implications for the management of carbon stocks and future carbon management projects.

Figures 14 and 15 illustrate the complexity of the flow-on effects of climate change.

Changes to the distribution of primary production will have socio-economic implications for individual businesses, industries, towns, schools and regions.

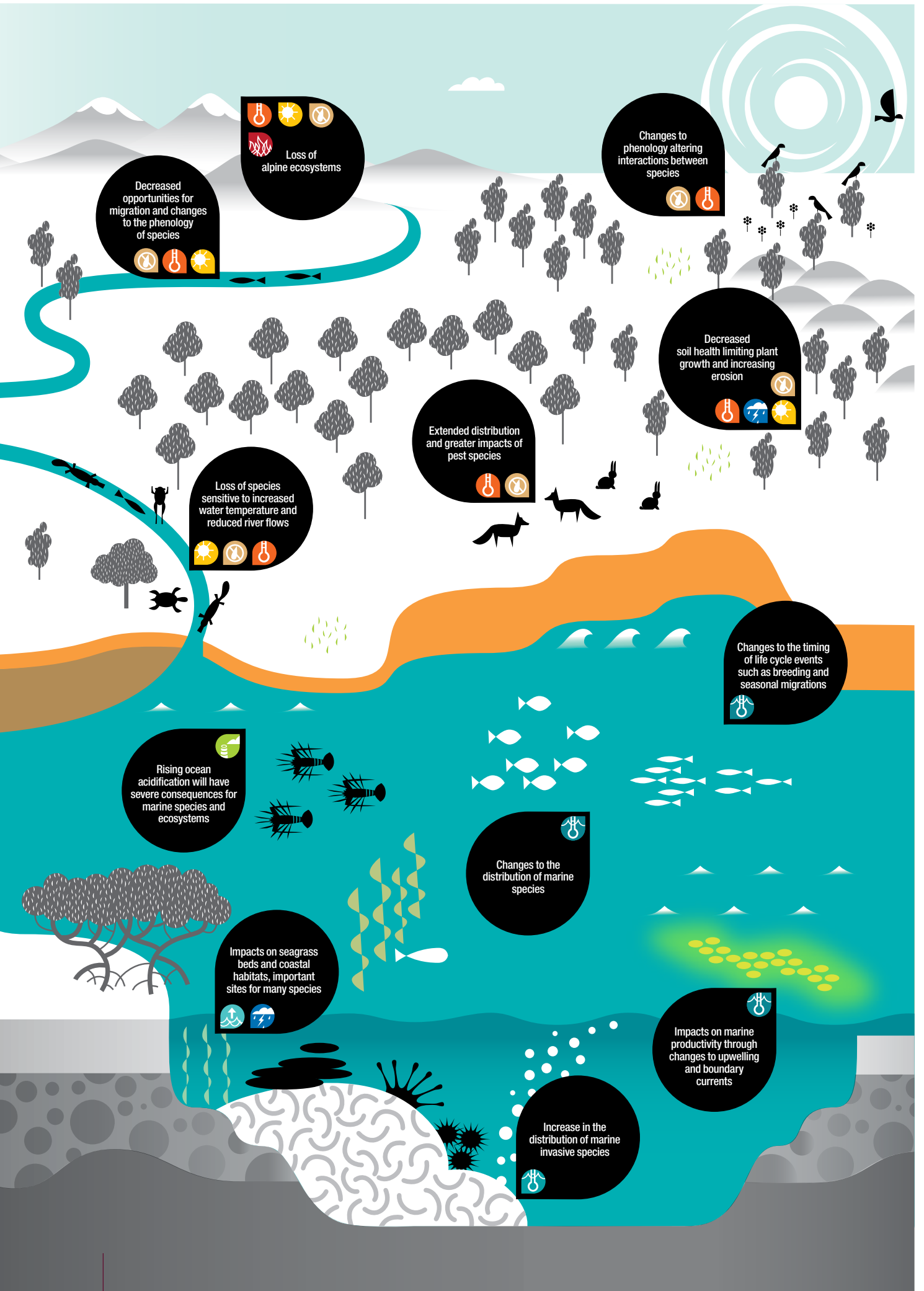


Mountain Ash.

Image courtesy of Department of Sustainability and Environment.



Figure 14: Impacts of Climate Change on Biodiversity.⁵⁷



Decreased opportunities for migration and changes to the phenology of species

Loss of alpine ecosystems

Changes to phenology altering interactions between species

Decreased soil health limiting plant growth and increasing erosion

Extended distribution and greater impacts of pest species

Loss of species sensitive to increased water temperature and reduced river flows

Changes to the timing of life cycle events such as breeding and seasonal migrations

Rising ocean acidification will have severe consequences for marine species and ecosystems

Changes to the distribution of marine species

Impacts on seagrass beds and coastal habitats, important sites for many species

Impacts on marine productivity through changes to upwelling and boundary currents

Increase in the distribution of marine invasive species

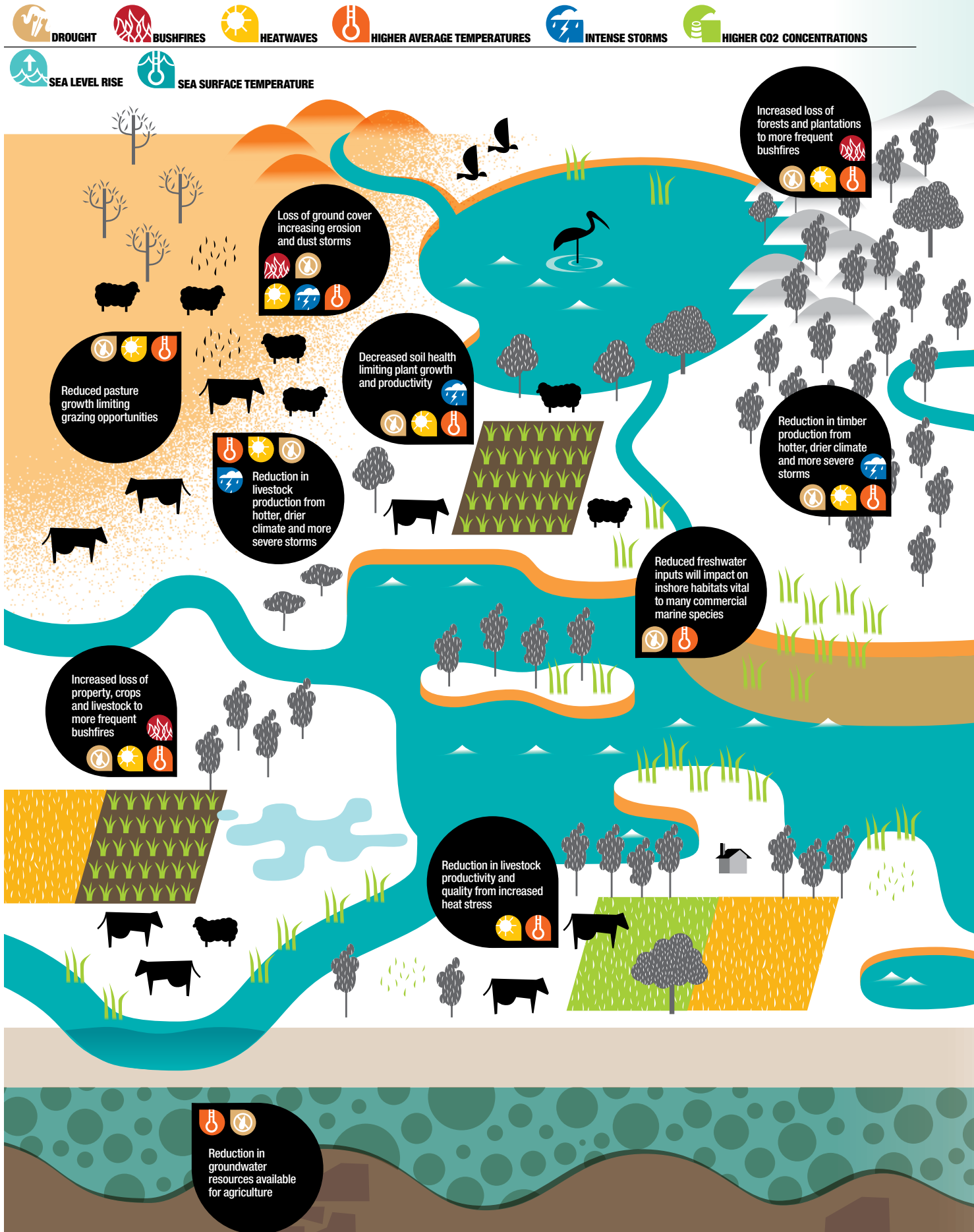


Figure 15: Impacts of Climate Change on Primary Production.⁵⁸



Reduction in water resources available for agriculture



Reduction in crop yields from hotter, drier climate and more severe storms



Increases in pests and disease reducing yields and raising management costs



Possible increase in crop and forestry yields when not limited by other climate change impacts



Relocation of agricultural industries to more suitable areas



Less frequent frosts reducing the yield and quality of crops that require chilling for production



Rising ocean acidification will impact on many commercial species



Migration or loss of marine species will affect the viability of current fisheries



Impacts on seagrass beds and coastal habitats important recruitment sites for many commercial species



Range extensions of marine pests such as Rock Lobster and Abalone



Victorian waters lie at the meeting point of the Southern and Pacific Oceans creating a unique environment that supports over 12,000 species of plants and animals, with 80% occurring nowhere else on earth.⁵⁹

2.2 Victorian Observations

Marine Ecosystems – South East Australia Hotspot for Biodiversity and Climate Change Impacts

Victoria's marine and coastal environment is one of the most diverse in the world.

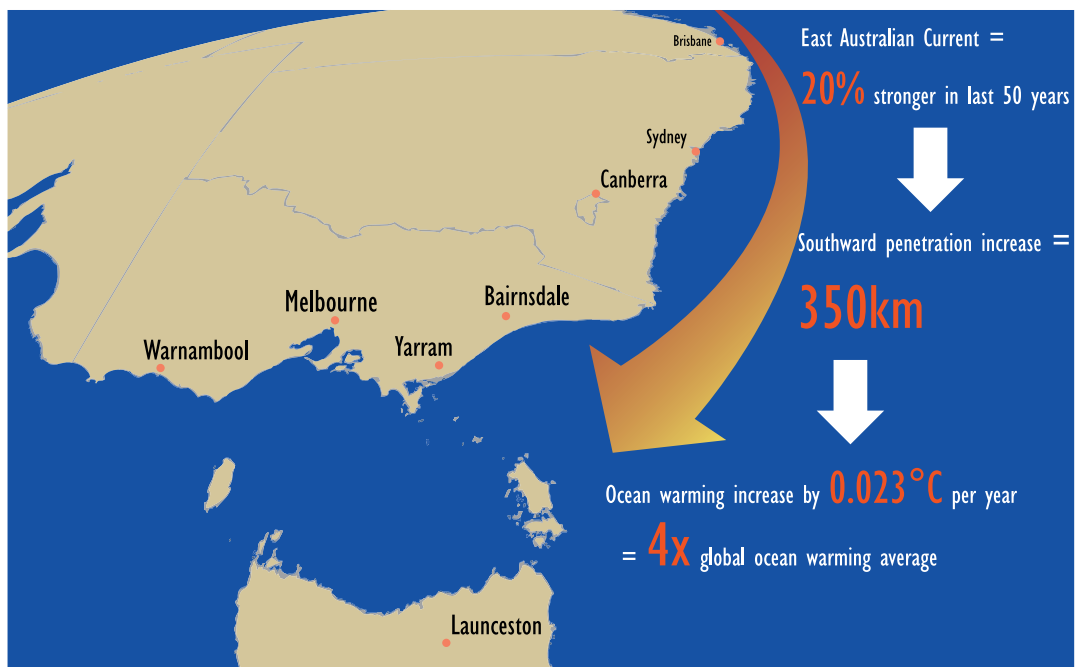
Victorian waters lie at the meeting point of the Southern and Pacific Oceans creating a unique environment that supports over 12,000 species of plants and animals, with 80% occurring nowhere else on earth.⁵⁹ Habitats include reefs, kelp forests, deep sponge gardens, sandy plains, seagrass meadows, and open water.

The marine and coastal environment provides many social and economic benefits for Victorians including recreation and tourism, and commercial fisheries. Recreational fishing alone is estimated to contribute over \$2 billion each year to Victoria's economy (this figure includes inland and marine fishing).⁶⁰

Victorian marine waters have been identified as being extremely vulnerable to climate change. In 2010, sea-surface temperatures in the Australian region were the highest on record.⁶¹ Southern Australia has experienced some of the fastest increases in ocean temperatures globally⁶² with sea surface temperatures shown to have risen 2°C off Australia's south east coast since 1925.⁶³

This rise in temperature is mainly due to the southern extension of the East Australian Current (Figure 16). Changes in climactic conditions have strengthened the current by 20% in the last 50 years,⁶⁴ increasing its southward penetration by 350 km.⁶⁵ The current brings warmer and saltier waters from northeast Australia down the east coast and its strengthening has caused warming at a rate of 0.023°C year, approximately four times the global ocean warming average.⁶⁶

The changes in current strength and rising sea temperatures are likely to have severe consequences for marine ecosystems in Victoria.



Other predicted climate change impacts include acidification, changes to wind patterns, sea level rise, and reduced inflows from inland waters.

Impacts of Climate Change on Victoria's Marine and Coastal Biodiversity

Climate change is likely to have profound effects on Victoria's marine and coastal biodiversity. Impacts will include changes in the distribution and abundance of species and habitats, local extinctions, changes to ecosystem function, connectivity and productivity.

The severity of the impact of climate change on marine and coastal ecosystems will depend on the ability of species to adapt to environmental changes. Of particular concern are impacts on phytoplankton and zooplankton species. These are key to marine food webs and changes to their distribution and abundance will have significant consequences for marine ecosystems.⁶⁸

Species unable to adapt will have to migrate to more suitable habitats.

It is predicted that a 1°C increase in ocean temperature may require some marine species to migrate hundreds of kilometres southwards to seek optimal conditions.⁶⁹ Major problems will be experienced by those species unable to move long distances, and species and ecosystems will be subjected to increased competition from new arrivals.

Of concern, even mobile species may find themselves with limited scope or ability to migrate because of the lack of suitable habitat to the south of the Australian mainland.⁷⁰

The impact of climate change on a species will also differ depending on life-stage. Marine species typically have complex life cycles requiring different habitats over time. For example, some fish species use mangroves and seagrass beds during juvenile stages and then move offshore as adults.⁷¹ Climate change in coastal waters and associated impacts on mangroves and seagrass beds will affect young life stages with flow-on effects for adult populations.

Figure 16:
Changes to the East Australian Current.⁶⁷
CfES developed infographic.



Grey Mangrove.

Image courtesy of Parks Victoria and Museum of Victoria.

Some of the associated changes in environmental conditions may enable some species to expand their range, providing new opportunities for fisheries.

However, not all species will be affected negatively by climate change, some of the associated changes in environmental conditions may enable some species to expand their range, providing new opportunities for fisheries.

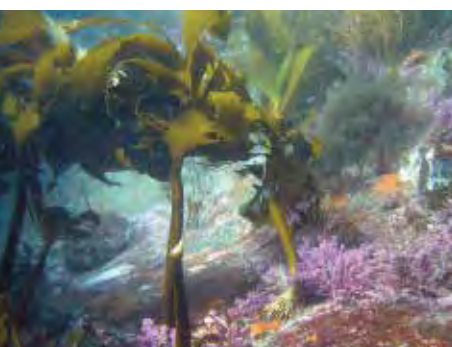
Recreational and commercial fishers have observed range expansions for pelagic fish species such as mahi mahi (*Coryphaena hippurus*), yellowfin tuna (*Thunnus albacares*), cobia (*Rachycentron canadum*) and stripey tuna (*Katsuwonus pelamis*).

Observed Marine Biodiversity Changes

Ocean warming has been observed as most pronounced in south-eastern Australia.

We have witnessed:

- the southern movement of seaweed to cooler waters, including range shifts of macroalgae and associated species and the decline of giant kelp (*Macrocystis pyrifera*)⁷²
- southward range extensions documented for 45 species of fish on the south-east coast, representing 15% of coastal fishes in temperate south-eastern Australia⁷³
- the sea urchin, *Centrostephanus rodgersii*, has extended its southern range by 160 km per decade over the past 40 years, from New South Wales to eastern Tasmania. Being a voracious grazer, the urchin has consumed vegetation, such as kelp forests, leaving behind bare rock⁷⁴
- a decrease in populations of the southern rock lobster
- changes to the distribution and abundance of estuarine habitats such as mangrove, seagrass and saltmarsh. Mangrove stands are increasing in area at the expense of saltmarsh, and seagrass habitats are declining. These coastal habitats are important as breeding or nursery areas, and this disturbance impacts a range of fish and other species.⁷⁵



Leathery Kelp - *Ecklonia radiata*.

Image courtesy Friends of Beware Reef.



MDN_Brittlestar (*Ophiomyxa australis*).

Image courtesy of Parks Victoria and Museum of Victoria.



MDN_Eelgrass (*Heterozostera* sp).

Image courtesy of Parks Victoria and Museum of Victoria.

The Black Bream - links between terrestrial and marine ecosystems

Many marine and coastal species are reliant on terrestrial processes linked through estuaries.

With climate change projected to reduce freshwater flows and terrestrial runoff in Victoria, inshore habitats are likely to undergo significant changes such as increased salinity, decreased nutrients and other inputs, and changes to estuary openings. This will have consequences for species that rely on inshore habitats for breeding, migrations, spawning habitats, and nursery areas.

Estuarine fish such as black bream (*Acanthopagrus butcheri*) are highly susceptible to changes in terrestrial rainfall. Black bream is important to both recreational and commercial fishers in the Gippsland Lakes. However, black bream catch in Gippsland Lakes has declined markedly over the last decade, due to drought.⁷⁶

The breeding cycle is complex. Research has shown that the Gippsland Lakes population of black bream is strongly linked to changes in river flows.

Black bream spawn in response to the location of the salt wedge and the length of the halocline which is the vertical stratification where freshwater and saline water meet. The salt wedge moves in response to freshwater flows in the river. Black bream then disperse their eggs in different locations along the river depending on where the salt wedge is located.⁷⁷

Under drought conditions, reduced river flows greatly decrease the potential spawning area of black bream.⁷⁸ Added to this is the impact of the movement of the saltwater wedge further upstream, as this increases the distance between suitable spawning and rearing habitats in the lake's seagrass beds.

Climate change will have significant implications for black bream populations with the likely further reductions in freshwater flows leading to increased estuarine salinity. Successful breeding of black bream in the future will depend on the location of the salt wedge in relation to suitable spawning/rearing habitats in the river.⁷⁹

This can be managed through the release of environmental flows to improve the success of black bream spawning, but will depend upon the availability of water for such flows.



Juvenile Black Bream.

Image courtesy Department of Primary Industries.

Ocean acidification will impact on commercial species such as rock lobsters.

Threats to fishery - primary production

Impacts on marine biodiversity and ecosystems will have significant consequences for Victoria's fisheries.

Predicted impacts include:

- As fishery distribution and abundance changes and ecosystems shift the sustainability and profitability of fisheries and associated industries will come under question.⁸⁰
- Range extension of species such as the sea urchin (*Centrostephanous rodgersii*) has serious implications for the sustainability of rock lobster and abalone fisheries in Victoria.⁸¹
- Ocean acidification will impact on commercial species such as rock lobsters.
- Increasing strength of south-easterly winds is likely to increase seasonal upwelling along the coast of western Victoria, leading to increased ocean productivity. This may improve fish stocks such as sardines off the coast of western Victoria but have significant adverse impacts on marine ecosystems.⁸²
- Changes in freshwater flows and terrestrial runoff will impact on commercial species that rely on inshore habitats for breeding, spawning habitats, and nursery areas.⁸³ Reduced freshwater flow events have been shown to affect estuarine fish catches, with drought conditions correlated to reduced catches.⁸⁴



Rock Lobster.

Image courtesy Friends of Beware Reef.

Management of Climate Change impacts on Victorian Marine Waters

To reduce the impacts of climate change, it is vital to address the existing pressures on marine and coastal ecosystems.

Stressors such as overfishing, invasive species and habitat disturbance are likely to exacerbate impacts of, and be exacerbated by, climate change, reducing the ability of species to adapt to environmental changes. Consequently, fishing regulation and habitat protection are key areas for adaptation strategies, for both biodiversity and primary production.⁸⁵

It is asserted broadly across the scientific community, both nationally and internationally, that one approach to improve marine biodiversity protection is through the extension of protected areas.

These areas can improve resilience. This allows populations to increase, both naturally and by the restocking of commercial fisheries (by protecting biodiversity and habitat and by providing marine refugia).

Victoria has 13 Marine National Parks and 11 smaller Marine Sanctuaries.

Currently these protected areas cover only 5.3% of Victoria's coastal waters, compared to 18% of protected areas of Victoria's land.

However, the extension of protected areas alone does not ensure the effective conservation of marine ecosystems because these areas can be compromised by a range of external pressures. For example, sea urchins have been linked to significant damage to protected areas such as Beware Reef in the south-eastern coast.

Therefore the management of pressures outside of protected areas is required. This includes the use of quotas and controls on fishing equipment to ensure the sustainability of fisheries, and the control of invasive species, particularly through the protection and restoration of natural predators.

Stressors such as overfishing, invasive species and habitat disturbance are likely to exacerbate impacts of, and be exacerbated by, climate change - reducing the ability of species to adapt to environmental changes.



Common Seadragons.

Image courtesy of Parks Victoria and Museum of Victoria.

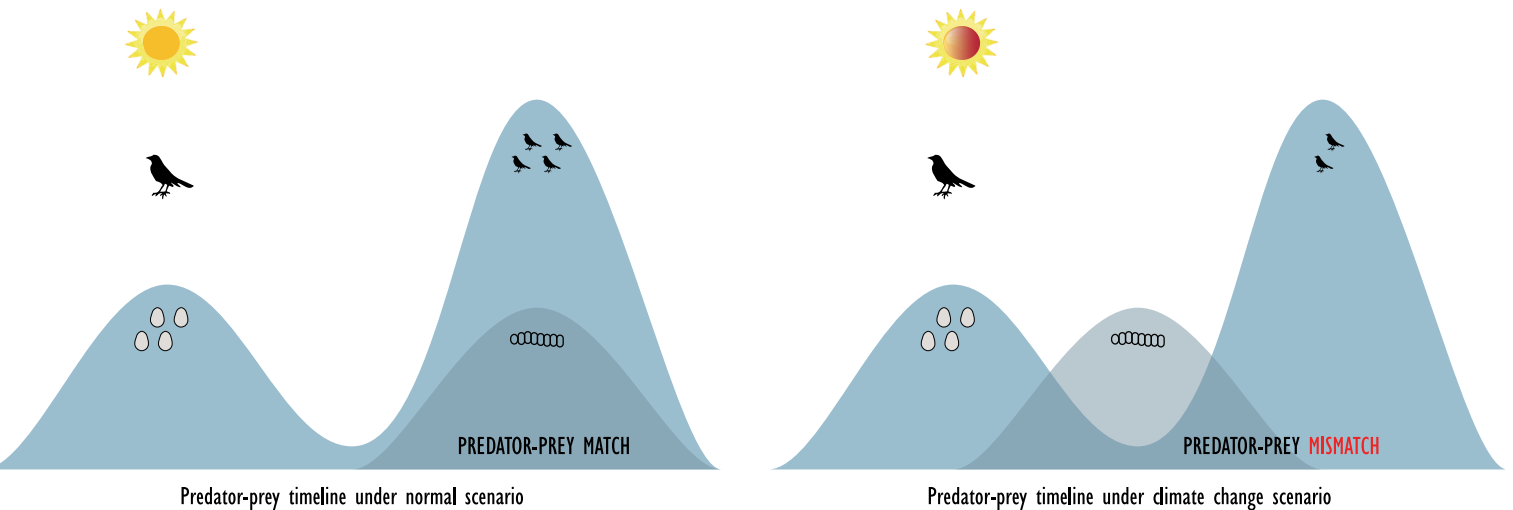
2.3 Observed phenology changes in Victoria

Phenology is nature’s calendar: the recurring plant and animal life-cycle stages such as the flowering, fruiting, egg laying, breeding and migrations. It is the study of these recurring life-cycle stages and their timing and relationship to climate and weather.⁸⁶

Why is Phenology Important?

Many species rely on the timing of life-cycle stages to ensure optimal environmental conditions for growth and breeding, such as abundant food for raising young or flowering to coincide with pollinator emergence.

Changes to phenology can severely disrupt food webs by altering competition between species and disturbing the timing of predator-prey relationships (Figure 17). Ecosystem function, reproduction success (e.g. fewer offspring), and reduced adult survival can be significantly impacted. Changes to phenological patterns not only impact biodiversity and ecosystem health, but this also impacts agricultural production and the availability of natural resources such as fish stocks.



Bird breeding is timed to correspond with the emergence of prey species, resulting in higher food availability and subsequently increased chick survival.

As the climate warms, prey species can emerge earlier, resulting in decreased food availability and chick survival.

Figure 17:
Climate change impacts on predator – prey relationships.⁸⁷

CfES developed infographic.

The life-cycle stages of plants and animals provide some of the strongest evidence for climate change impacts on the environment and primary production. Phenology information can determine changes in the timing of seasonal activities and inform us about whether individual species and those they interact with are responding together or separately.

This information is vital for the effective management of natural resources as we contend with climate change.

The Victorian Experience of Phenological Change

Although the knowledge of phenology is poor in Victoria, examples of life-cycle changes associated with anthropogenic climate change are becoming evident.

Across Victoria, some 22 bird species and 46 plant species have been identified as having modified life-cycles in response to a warming climate.⁸⁸ Because these findings are based on limited assessments of those species with available data, the actual number of Victorian species with modified phenologies remains unknown.

For those species that have not demonstrated a shift in their phenology, it is unclear whether this is because they are unable to do so, or whether the climate threshold which will trigger a change has yet to be reached.

Phenology changes are also impacting Victorian agricultural harvests. For example, the yields of stone fruits, pear and apple trees rely on chilling to stimulate the bud break required for fruiting. In warmer years, reduced chilling has resulted in prolonged dormancy and reduced fruit quality and yield.

Climate change is also impacting on the Victorian grape and wine industry. For example, earlier grape flowering has impacted on wine quality due to advanced harvest dates. In southern Australia, wine grapes have been ripening earlier with grape maturation dates advancing about eight days per decade (1985–2009).⁸⁹ Increased warming and declines in soil water content have been identified as major drivers of this ripening trend.⁹⁰ Further warming is expected to significantly affect grape quality, leading to a decline in grape prices of up to 50% in some areas of Victoria.⁹¹ Such changes are likely to lead to the development of new wine-growing regions and the planting of different grape varieties to adapt to climate change.

Phenology changes also impact on human health. Earlier and prolonged flowering of Victoria's plants has been documented as being linked to an increase in the occurrence of asthma, hay fever, allergic conjunctivitis and eczema.

Across Victoria, some 22 bird species and 46 plant species have been identified as having modified life-cycles in response to a warming climate.⁸⁸

Nesting penguins spend considerable amounts of time on land in burrows, exposing them to high temperatures.

Phenology Case Studies

A: Impacts of Climate Change on Little Penguins, Phillip Island⁹²

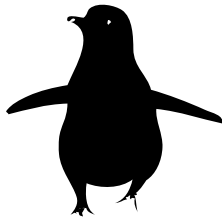
Little penguins (*Eudyptula minor*) at Phillip Island are one of Victoria's most popular attractions, generating hundreds of millions of dollars in tourism. This population has been monitored since the late 1960s and strong links are clearly evident between breeding timing and environmental conditions (Figure 18).

Timing of egg laying in this species is associated with regional sea surface temperatures. Warmer waters promote an earlier start to the breeding season. The timing of breeding has important implications for the population of the Phillip Island colony.

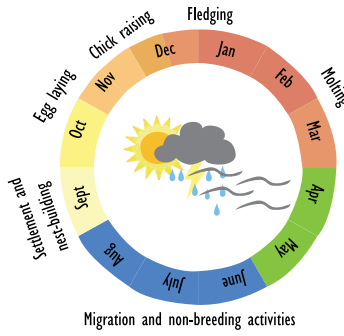
In those years where early breeding took place due to warmer temperature, more chicks were produced per pair. Chicks produced at this time were also heavier, increasing their chance of survival. In the years when breeding was delayed, the opposite was true. This would suggest that as Bass Strait warms, this penguin colony will thrive, at least in the immediate future.

However, the warmer conditions that lead to increased sea surface temperatures can also have negative impacts on little penguins. Nesting penguins spend considerable amounts of time on land in burrows, exposing them to high temperatures. Although their burrows provide some insulation, little penguins, like many seabirds, struggle with heat stress and mortality rates increase with prolonged exposure to air temperatures above 35°C. The associated increase in risk of exposure to fire, a significant threat to the survival of populations of little penguins, also rises with a warming climate.

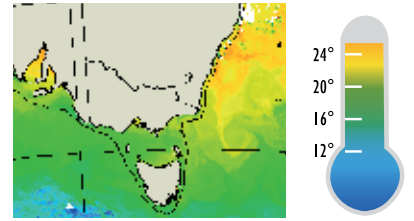
To overcome these risks, management actions including shading by increasing vegetation cover and appropriately designed and insulated artificial nesting burrows, significantly decreases such risks.



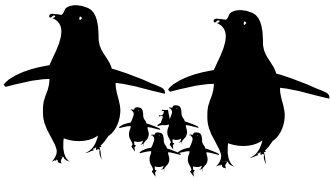
Phillip Island Little Penguins are a popular tourist attraction, generating hundreds of millions of tourism dollars for Victoria



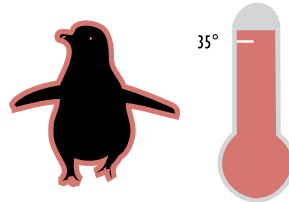
Monitoring of penguin populations since the late 1960s reveals a strong link to environmental conditions



Warmer sea surface temperatures correspond with an earlier start to the breeding season



Earlier breeding produces more and healthier chicks, however, climate change can also have a negative impact on nesting



Nesting penguins spend more time on land and in burrows, where heat stress and mortality can occur with prolonged exposure to temperatures above 35°C. Exposure to bush fires is also increased



Fortunately, monitoring and management, such as shade plantings and insulated artificial nesting burrows, can help decrease these risks

Figure 18:
Differing impacts of climate change on Little Penguins.⁹³
CfES developed infographic.



Little Penguin.

Photo: © The State of Victoria, Department of Sustainability and Environment/McCann).



Red Ironbark.

Image courtesy of Elizabeth Donoghue.

B: Red Ironbark Flowering⁹⁴

Red ironbark (*Eucalyptus tricarpa*) is a eucalypt species found in Victoria’s dry box-ironbark forests and woodlands. Unusually, the red ironbark flowers throughout winter, providing a food source for many woodland birds, including the endangered Swift parrot (*Lathamus discolor*). Box-ironbark forests, including flowering red ironbarks, also produce 70% of Victoria’s honey.

Between 1930 and 1981, the Forest Commission recorded the flowering and budding of red ironbark across Victoria. A study of these records showed that cooler maximum temperatures and wetter conditions clearly increased flowering. A further study also established that red ironbark flowering in the Rushworth Forest between 1945 and 1970, peaked mostly in June and that no flowering was recorded in 4 of the 26 years of study.

Between 1997 and 2007 woodland bird numbers and flowering events were studied in the Rushworth Forest. Warmer temperatures resulted in the failure of flowering in 4 of the 11 years under study. Three of those failures occurred between 2002 and 2007.

In response to changes in flowering frequency, the study showed that the population of woodland birds declined significantly.

Improving Phenology Knowledge

Phenology is a sensitive and easy to observe indicator of climate change. However, compared to the northern hemisphere, Australia has few long-term life-cycle studies. Work is underway to improve our knowledge of species responses to climate change.

One such initiative is ClimateWatch, Australia’s citizen science phenological observation network (www.climatewatch.org.au). This is a major step for Australia. It provides a coordinated national indicator program to monitor the impacts of climate change.

As with other citizen science efforts discussed in this chapter, Climatewatch provides an important opportunity for Victorians to participate in climate change research, increasing awareness, understanding and knowledge of climate change impacts.

As with other citizen science efforts discussed in this chapter, Climatewatch provides an important opportunity for Victorians to participate in climate change research, increasing awareness, understanding and knowledge of climate change impacts.

2.4 Forest systems: climate change impacts on carbon storage⁹⁵

Forest ecosystems play an important role in the global carbon cycle and global greenhouse gas balance by storing carbon in both trees and soil.

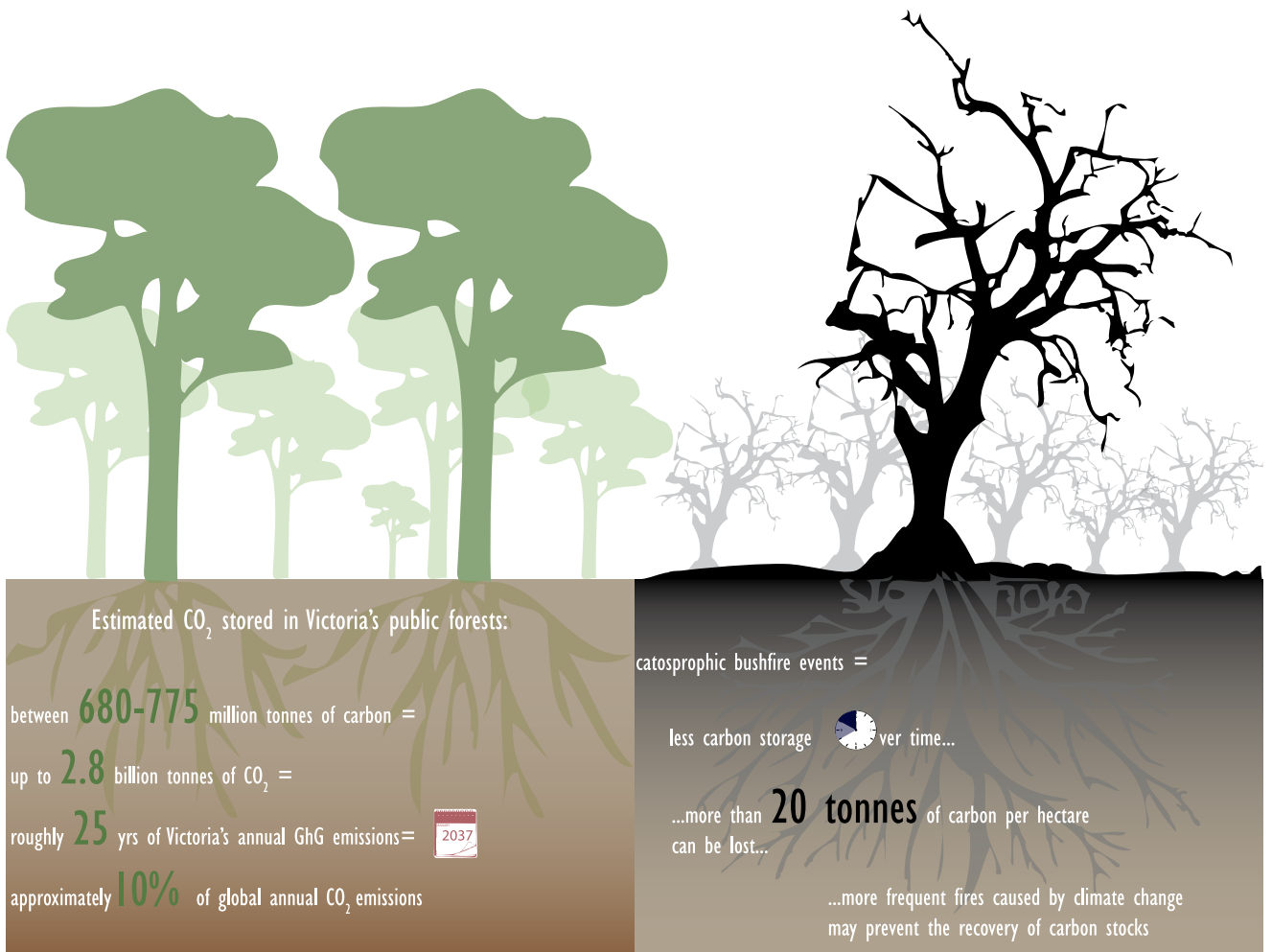
Carbon storage is dependent on a range of factors which are impacted by climate change, such as rainfall, soil moisture, nutrient availability, and disturbances such as bushfire. Land-use change (permanent clearing) and forest harvesting also affect carbon storage.

Victoria's forests store a considerable amount of carbon. In 2010, Victoria's carbon stock for publicly managed forested land was estimated between 680 and 775 million tonnes of carbon (or up to 2.8 billion tonnes of carbon dioxide equivalent). This represents roughly 25 years of Victoria's total annual greenhouse gas emissions (Figure 19).

Figure 19:
Impacts of bushfire on carbon storage in Victorian forests.

CfES developed infographic based on Department of Sustainability and Environment information.

a tale of two forests



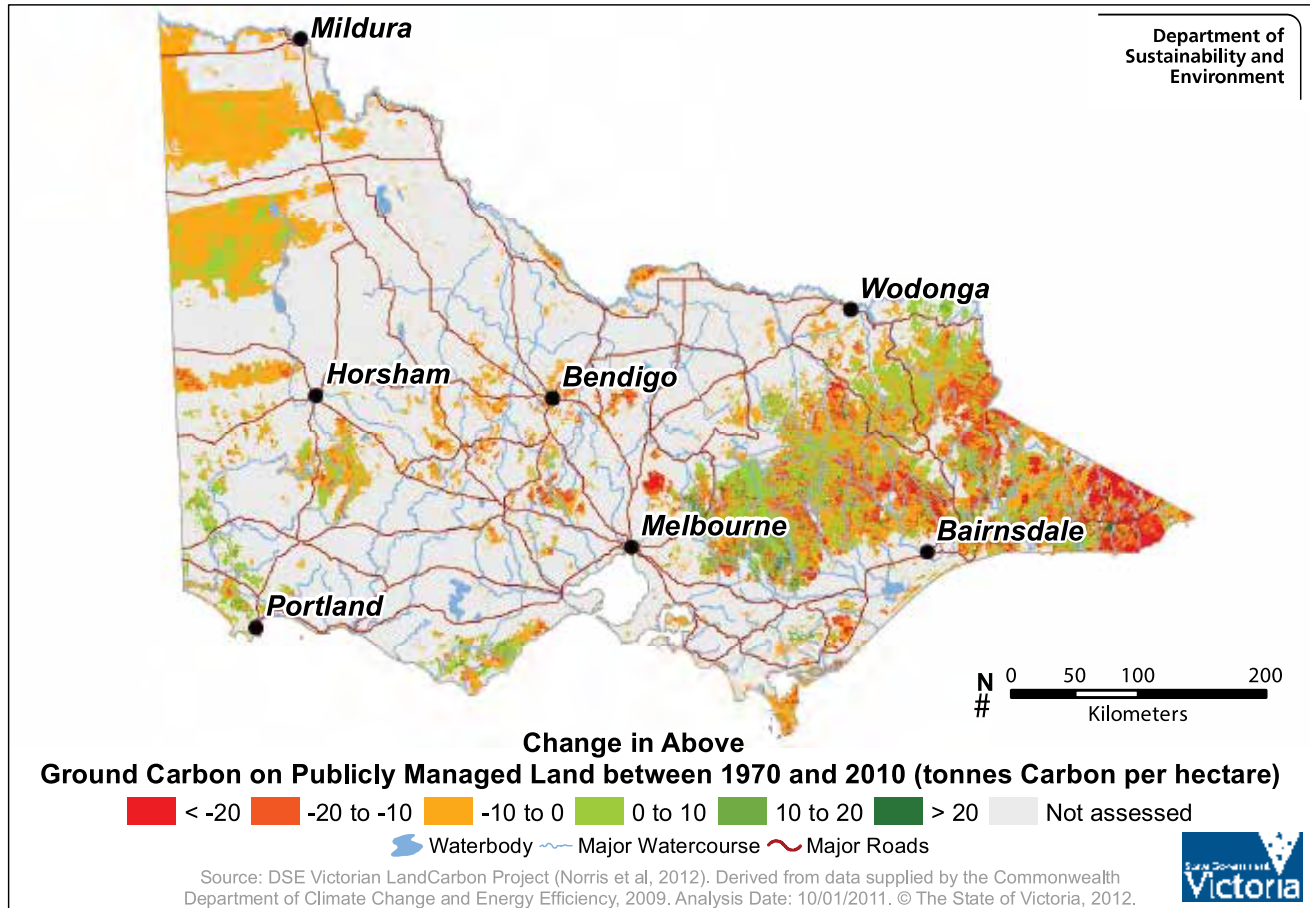
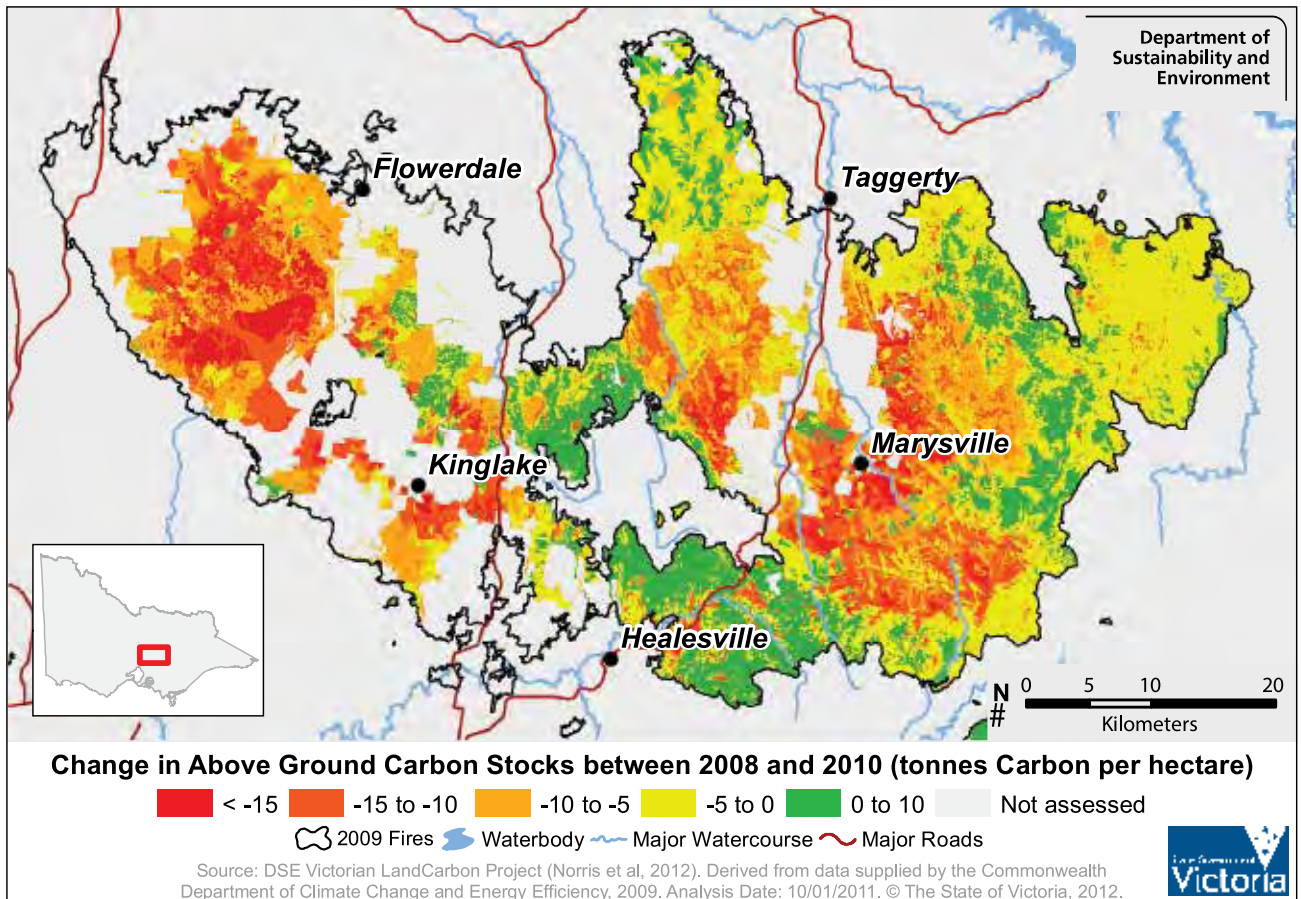


Figure 20:
Change in above ground carbon on publicly managed land between 1970 and 2010 (tonnes carbon per hectare).
 Source Department of Sustainability and Environment.

The map in Figure 20 shows the changes in the modelled total above-ground carbon stock for Victoria’s public land estate between 1970 and 2010. A strong west-to-east and north-to-south trend is evident. This largely follows the rainfall gradient.

In addition, the impact of recent fires appears across the Central Highlands and Alps, which have relatively low carbon stocks when compared to the largely unburnt areas of the State in East Gippsland and the Strzelecki Ranges.



The map in Figure 21 shows the area affected by the 2009 Black Saturday bushfires (revealed by showing the change between 2008 and 2010). The effect on carbon stocks resulting from a catastrophic bushfire event is considerable, with a change of more than 20 tonnes of carbon per hectare in some areas.

Whilst the post fire recovery of forests will increase carbon stocks, the projected increase in the occurrence and severity of fire as a result of climate change is of particular concern. It is unlikely that Victoria's forests can remain resilient to the impacts of increased fire frequency. Exceeding ecological fire tolerances would likely result in forests being altered in terms of structure, dominant species, and function, potentially storing less carbon over time.

Carbon stocks in Victoria are vulnerable to climatic variation and the occurrence of bushfires. This has important implications for the management of Victoria's carbon stocks with the ability of forests to take up carbon vital for the mitigation of climate change.

Figure 21: Change in Above Ground Carbon Stocks between 2008 and 2010 (tonnes Carbon per hectare).

Source Department of Sustainability and Environment.



River Red Gums.

Image courtesy of Department of Sustainability and Environment.

2.5 Responding to climate change

Community-based environmental management and monitoring

Some 61% of Victoria's land is privately owned and managed. Community action is key to promoting resilience and adapting to the impacts of climate change on Victoria's environment.

The community already undertakes a variety of roles including on-ground works and monitoring.

Where government works closely with the community environmental management is improved and climate change adaptation will be more effective, embedded and swifter.

Building Ecosystem Resilience

Community Natural Resource Management

Victoria has a range of community-based land management and restoration organisations including individual Landcare collaborations (e.g. Project Platypus and the Blackberry Taskforce), Greening Australia, Trust for Nature, and Bush Heritage, as well as many private landholders who undertake their own management.

These groups undertake a range of works including restoration of habitat and control of pest plants and animals.

Multiple benefits, including building the resilience of natural ecosystems, improving land health, biodiversity conservation, increasing the area and connectivity of natural habitat, and increasing carbon capture possibilities flow on from these efforts, all of which are vital for addressing the impacts of climate change.

Some 61% of Victoria's land is privately owned and managed. Community action is key to promoting resilience and adapting to the impacts of climate change on Victoria's environment.

The value of community-based monitoring has been demonstrated by groups such as Waterwatch, ClimateWatch (see phenology section), Birds Australia, Sea Search, Reef Life Survey and Two Bays programs.

Building Knowledge - Community Monitoring

Effective and informed management of climate change impacts will rely on the availability of comprehensive data on environmental change and condition.

Information on the impacts of climate change on Victorian biodiversity and natural ecosystems is sparse, particularly in areas where access is limited. Marine ecosystems are particularly problematic and many knowledge gaps exist.⁹⁶ High quality community based monitoring can help address such knowledge gaps.

The value of community-based monitoring has been demonstrated by groups such as Waterwatch, ClimateWatch (see phenology section), Birds Australia, Sea Search, Reef Life Survey and Two Bays programs. Landcare groups and networks, along with individual volunteer Landcarers also contribute to the monitoring efforts. These community-based monitoring programs complement the work of government agencies, increasing the frequency and coverage of environmental observations, greatly improving the likelihood of the early detection of impacts and identifying the need for further investigation and management responses.

Early detection is critical for the effective management of climate change impacts such as changes in the distribution and abundance of species.

Citizen Scientists

Dedicated community group work is augmented by the citizen science efforts of bushwalkers, campers, bird watchers, recreational fishers, and even scuba divers. Reporting unusual observations such as the presence of new species, the absence of once common ones, or changes in ecosystem health such as the condition of vegetation, can help scientists understand the impacts of climate change.

To support citizen science, environmental agencies need to provide user friendly reporting structures for observational data.

Publicly accessible databases would encourage participation in citizen science, and well maintained databases would facilitate analysis of these community observations by scientists and environmental managers.

Case Study: Community Monitoring of Marine and Coastal Ecosystems⁹⁷

Sea Search and the Reef Life Survey, which partner with Deakin University and the University of Tasmania, provide an insight into the value of formal programs. Community and government agencies work to ensure quality marine and coastal monitoring outcomes which can then be incorporated into the management of marine parks and ecosystems.

Benefits include tracking the long-term impacts of climate change, information which will be of enormous value for the ongoing management of climate change impacts. Objectives include the promotion of environmental stewardship and education as well as the monitoring of natural values. Partnerships between recreational divers, research scientists, coastal managers and other citizen science programs are also strengthened.

Participants:

- explore the health of seagrass, mangroves, and intertidal and subtidal reef ecosystems
- provide early detection of threats like invasive species, poor water quality, and species range expansions
- monitor population trends for management of threatened species
- provide mapping and biodiversity surveys.

Success attends these two programs. Pests like the Long-spined Sea Urchin have been detected. Managers have become alert to the collapse of the Southern Rock Lobster population. Migration of northern species into southern waters has been mapped. A decline in Broad-leaf Seagrass (*Posidonia australis*) has been recorded. Increases in minimum winter water temperatures – a precursor to other work about climate change impacts – has been noted and reported.



*Friends of Beware Reef.
Images courtesy Friends
of Beware Reef.*

Fish species that inhabit the reef permanently or in transit are monitored, along with mobile invertebrates such as starfish, urchins and nudibranchs.



Black Urchin
- *Centrostephanus rodgersii*.
Image courtesy Friends of Beware Reef.



Short-tailed Sea Slug.
Image courtesy of Parks Victoria and Museum of Victoria.

Quality data, vital to scientific study and management, is routinely collected by these scientifically rigorous programs. Participants are trained, and quality control is exercised on all the aspects of the programs. Scientists provide ongoing assistance. Data collected by volunteers has been assessed as either comparable to that collected by scientists, or of a quality to inform the management practices of Victoria's marine parks.

Community members report the satisfaction they gain from being involved in such programs. *Friends of Beware Reef* is a *small* group of surveyors which prides itself on its local roots, is easily deployable in windows of good weather, and provides rigorous and credible data with scientific bona fides. A supervised dive and survey camp training program has been followed by assessment and evaluation. Checking of skills and data is scrupulous and ongoing.

Fish species that inhabit the reef permanently or in transit are monitored, along with mobile invertebrates such as starfish, urchins and nudibranchs.

Once collected, the data is available for use by scientists, parks management, planners and other interested agencies. To date the *Friends of Beware Reef* has documented:

- the proliferation of the Long-spined Sea Urchin along the length of the East Gippsland coast
- the colonisation of southern coastal reaches by warmer water northern species including the Round-belly Cowfish, Gunther's Butterflyfish, Girdled Scalyfin, Small-Scale Bullseye, Kapala Stingaree, turtles, sea snakes, and Blue-black Coral
- algal events becoming more common due to the upwelling of cold nutrient rich water off the continental shelf
- increasing minimum winter water temperatures - by as much as 13.5 degrees in one year
- the apparent collapse in the southern rock lobster population
- locating one exotic species of sea star - the Seven-arm Sea Star, (*Astrostole scabra*.) a New Zealand species.

'Education' about the marine environment is core business for the *Friends of Beware Reef*. Presentations (up to 30 per year) to the public, poster production, promotional and information rich video representations have been provided and the fish and invertebrate data base which they developed is continually updated.

It is the local roots of the *Friends of Beware Reef* which makes their work in this isolated and challenging environment absolutely invaluable to assist us to understand biodiversity susceptibility to climate change in this marine hotspot on Victoria's south eastern coast.

CHAPTER **THREE** - SUSCEPTIBILITY OF THE BUILT ENVIRONMENT

Two hundred years of European settlement has established infrastructure which has coped with climate extremes. Plenty of life remains in major infrastructure such as the Snowy Hydro Scheme (construction began 1949), the Eildon Weir (1951), the West Gate Bridge (1968) and the Thompson Dam (1976).

However, much of our social and economic activity now depends on infrastructure which was built for a climate that will be subject to significant change. Current construction must respond to present and future needs, and present and future climate conditions.

If the Eureka Tower in Melbourne lasts as long as the Royal Exhibition Building (1880) has already, it will have to deal with the climate of the year 2144. Major infrastructure decisions will need to take into account future climate, even as we struggle to understand exactly what that climate will be at the end of its life. Future uncertainty can be addressed by deliberately shortening time horizons - building something to last for a shorter length of time, knowing it can be replaced relatively easily in the future. However, this is not always an efficient option. Another option might be to plan and build infrastructure which can be easily retrofitted as conditions change, as this could provide efficiencies.

All our cities, and all our rural infrastructure networks, are challenged by climate change eventualities.

If the Eureka Tower in Melbourne lasts as long as the Royal Exhibition Building (1880) has already, it will have to deal with the climate of the year 2144.

Extreme events that impact on our built environment are a part of life in Victoria. Such events have always happened, and always will. What is at issue is the increased intensity of these events as the climate changes.

3.1 Extreme weather events and our infrastructure

Direct Impacts

On the night of 13 January 2011, residents of Halls Gap were warned that they might be cut off by rising flood waters.⁹⁹ Almost 300 mm of rain hit the town in the space of three days,¹⁰⁰ triggering widespread landslides through the world-famous Grampians National Park. Kilometres of road and many vehicle and pedestrian bridges were laid to waste.¹⁰¹ Major rainstorms in the area sparked a trail of devastation across much of the north-west of the state (see Chapter Four).

Severe rainstorms also cause havoc in cities.

In Melbourne on 6 March 2010, roofs collapsed, houses were flooded, trains failed to run, and 100,000 houses in the city lost power. The insurance bill was calculated to be over \$1 billion – essentially the same as the Black Saturday bushfires.¹⁰² All this was caused by 26 mm of rain and hail falling in less than an hour.¹⁰³

An event of this intensity is considered a one-in-ten-year storm – put another way, it has a 10% chance of occurring every year. A similar storm occurred in Melbourne in February 2011 and resulted in insurance claims of \$384 million.

Storm-induced erosion and king tides are already causing damage to our built environment. The Seaspray Surf Life Saving Club in West Gippsland is built on coastal dunes and, following storms in 2007, is being relocated to prevent it from toppling into the ocean.¹⁰⁴ In Fairhaven on the Surf Coast, a beach access ramp has been destroyed. It is suggested this is a harbinger of worse things to come.

Heatwaves, another extreme weather event, cause extensive damage to physical infrastructure. In late January 2009, temperatures spiked over 43 degrees on three consecutive days in Melbourne. Across the other side of the continent, Perth has undergone eight heatwave events since November 2011 (BoM) and that city experienced a record of consecutive days in excess of 30 degrees in the summer of 2010/11.

The strain on the electricity system in Melbourne in 2009 due to the record demand for cooling was exacerbated by a heat-related explosion that crippled two 500 kV power lines just north of Melbourne at South Morang. Power was cut for several hours to over 500,000 people, equivalent to 10% of the state. At the same time, across the state, train tracks were buckling and roads were melting.

Extreme events that impact on our built environment are a part of life in Victoria. Such events have always happened, and always will. What is at issue is the increased intensity of these events as the climate changes.

Beyond the extreme weather events we are also told to expect gradual changes, such as sea-level rise, rising temperatures and elevating CO₂ levels - beyond IPCC projections - bringing a range of new threats (Figure 22).

As a community, we will have to develop new ways of thinking about managing our urban environments and service infrastructure. Such challenges require serious consideration in all sectors of government, business and society generally. Our thinking and action will need to be collaborative and constructive.

Such challenges require serious consideration in all sectors of government, business and society generally.

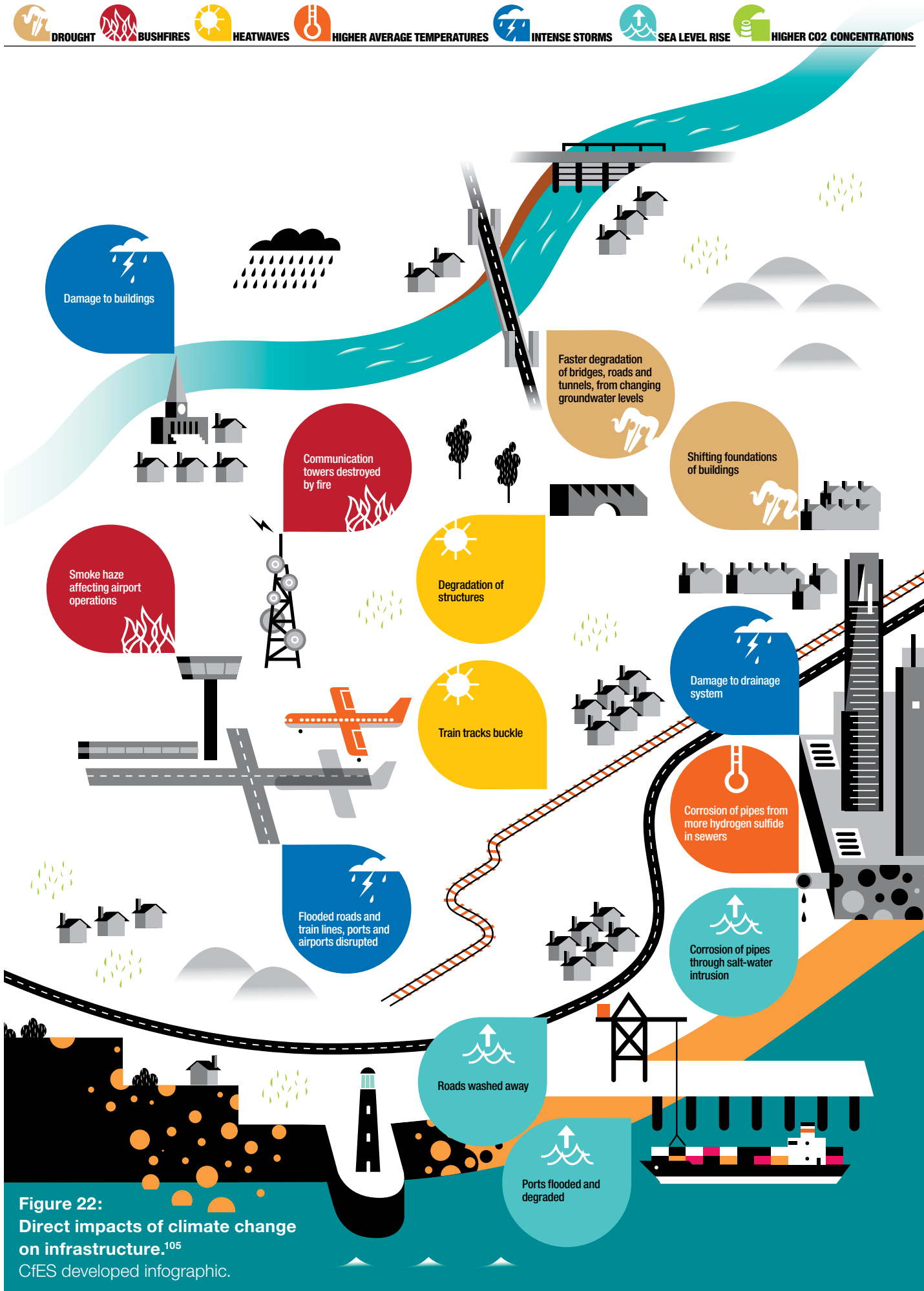
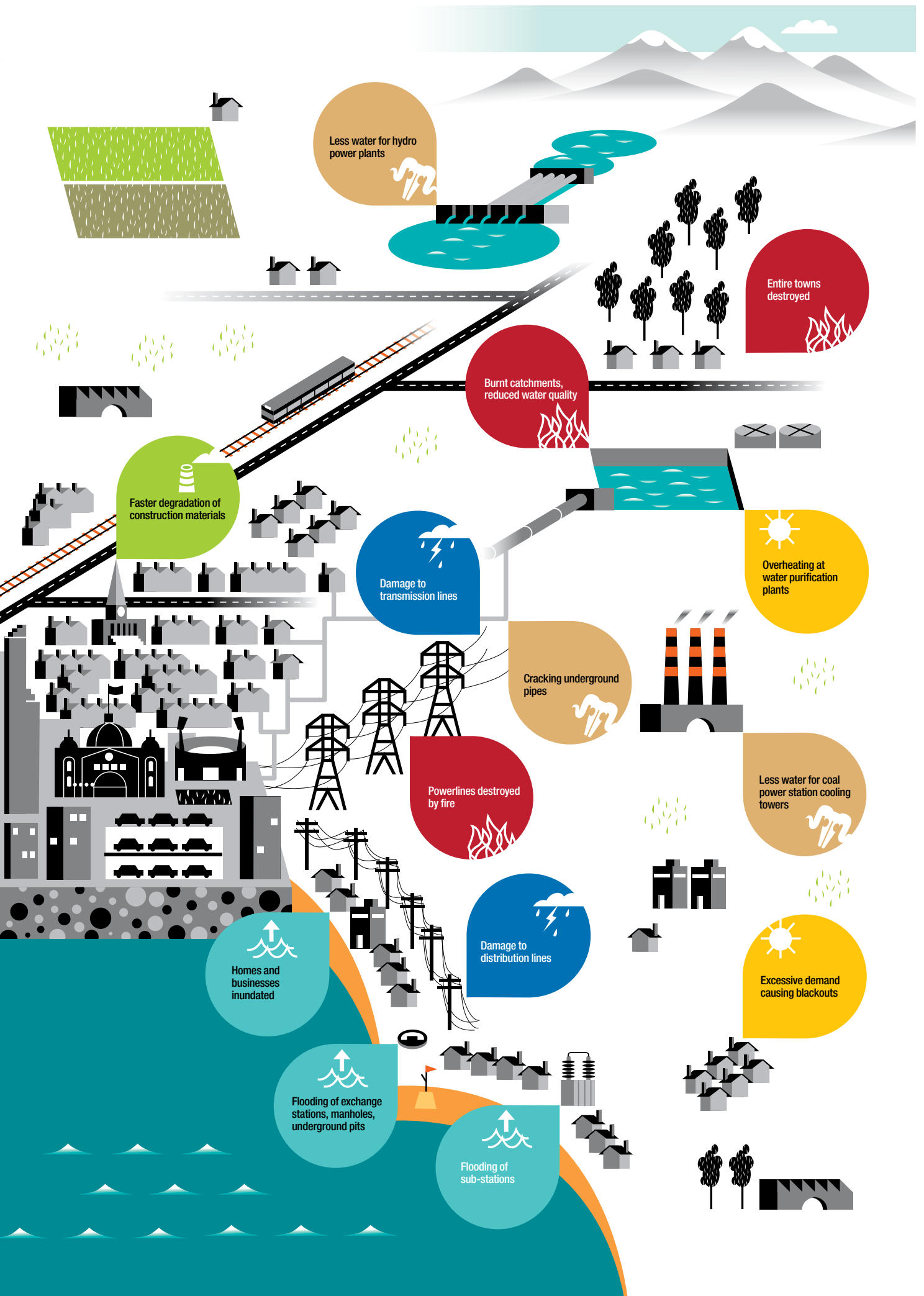


Figure 22:
Direct impacts of climate change on infrastructure.¹⁰⁵
CfES developed infographic.



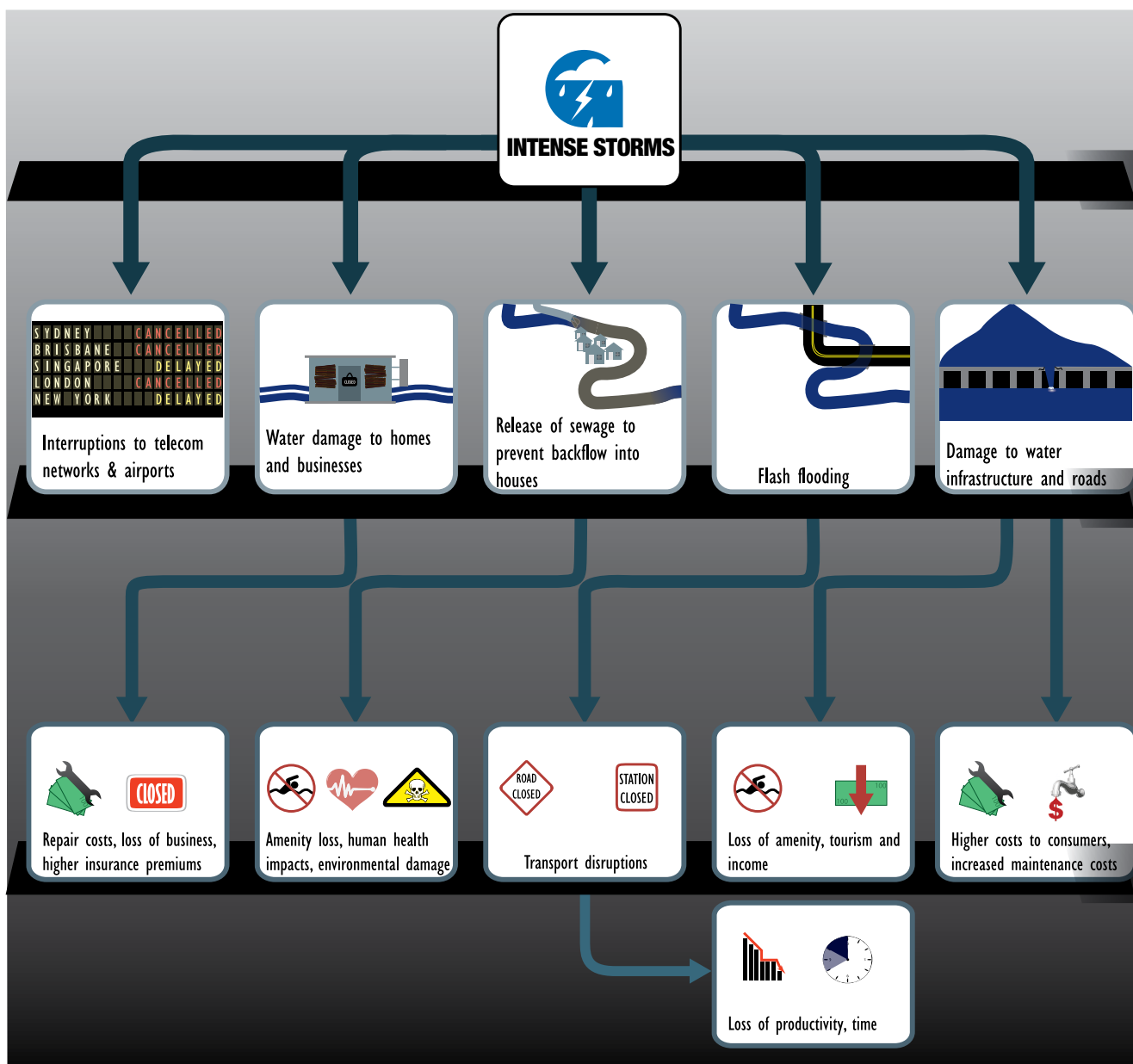
It is not just the owner of the buckled train line who bears a cost; so will the stranded commuters.

Cascading impacts

Disruptions of the kind described above will have socio-economic impacts that affect many more people than just those who own damaged property (Figures 23A-C). It is not just the owner of the buckled train line who bears a cost; so will the stranded commuters. When heavy rain damages drainage infrastructure and causes flooding over roads, businesses are affected by disrupted logistics and supply chains, especially when relying on “just-in-time” delivery of goods.¹⁰⁶ This is because our society has evolved with a dependence on the *function* of the built environment and its service infrastructure.

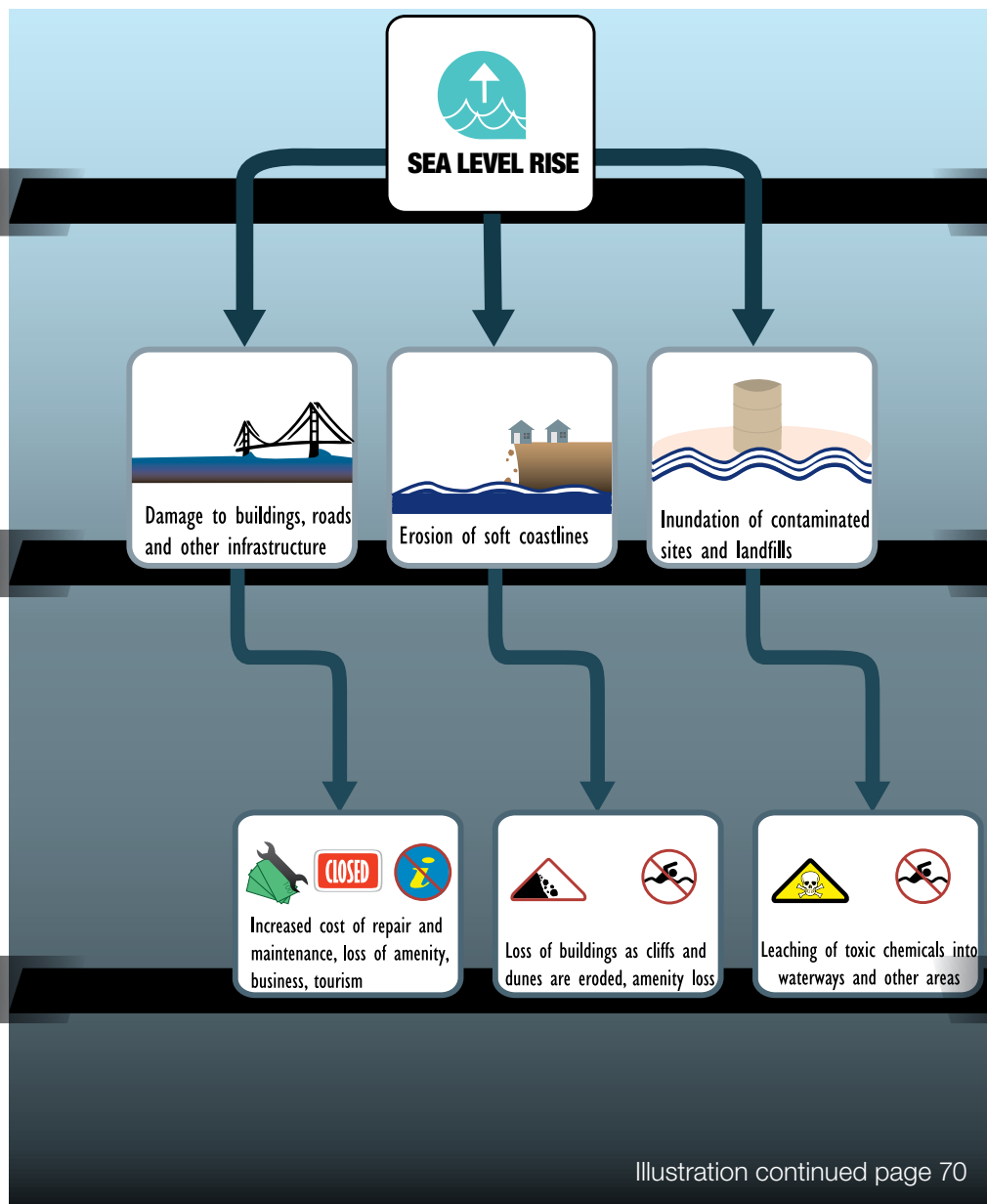
Figure 23_A:
Cascading Impacts.

CfES developed infographic.¹⁰⁸



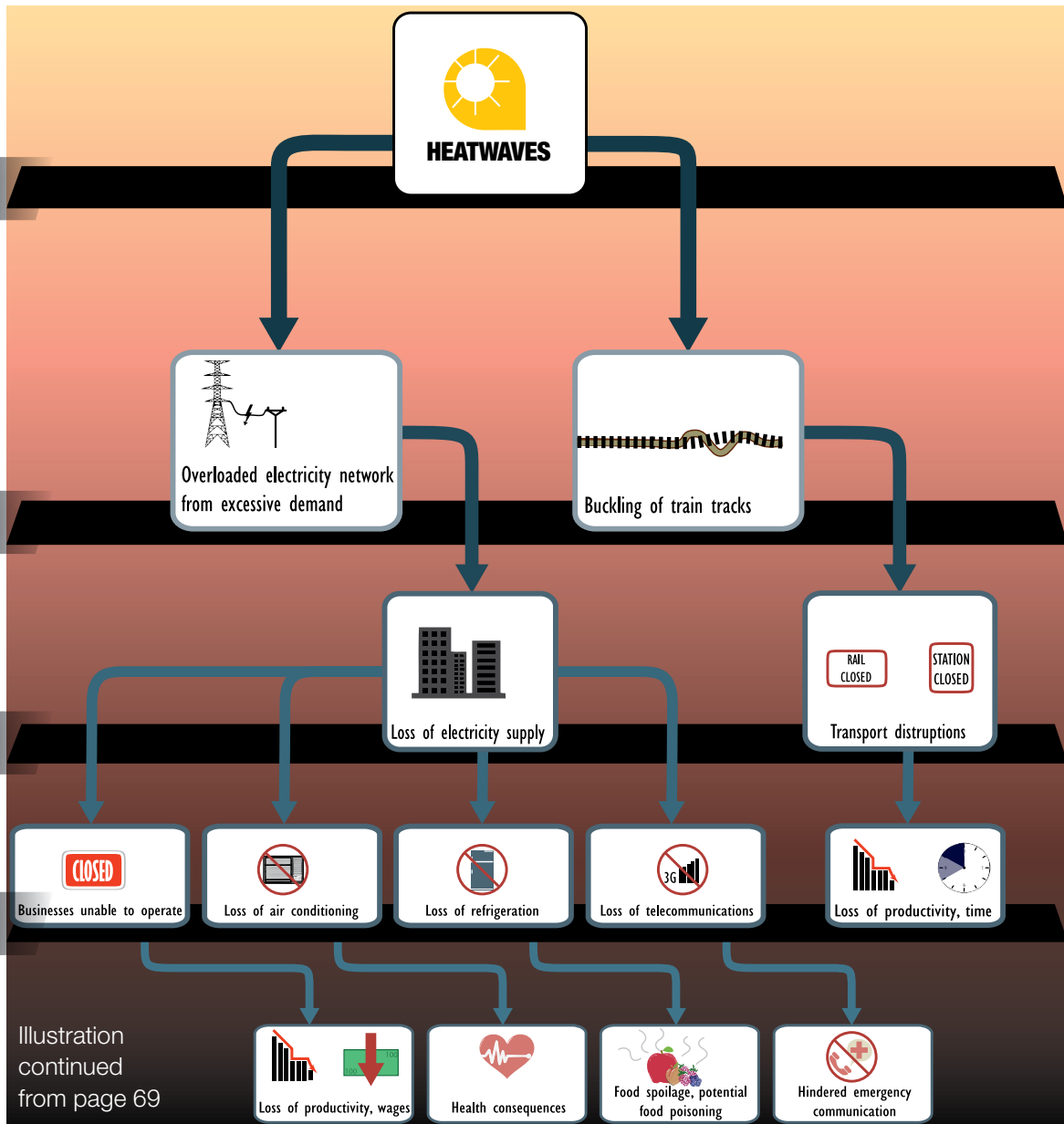
Critical infrastructure functions are increasingly inter-dependent, as well as being intimately linked to our social and economic structures.¹⁰⁷ Assessment of the economic damage of these cascading impacts is imprecise. The imprecision of financial evaluation does not diminish the cascading impacts and their importance.


Figure 23_B:
Cascading Impacts.
CfES developed
infographic.¹⁰⁸



Costs of disruption of infrastructure by extreme heat ¹⁰⁹	
16 January 2007	\$501 million
29-30 January 2009	\$800 million

Figure 23_C: Cascading Impacts.
CfES developed infographic.¹⁰⁸





One infrastructure impact of the 2011 floods through northern Victoria was the breaking of the Dimboola weir by a swollen Wimmera River. The weir, previously needed for water storage purposes, has been superseded by the Wimmera-Mallee pipeline and there is little incentive to repair it for water management purposes.

For the townspeople, however, the presence of water in the river has a strong link to recreation, tourism and socio-economic outcomes. Tourists “come in droves” when there is water in the river – “it’s like a magnet”

(Rodney Lehmann, Dimboola Rowing Club President).

In particular, the Dimboola Regatta is a major event in the local calendar, and it was threatened by the absence of a weir to keep the water level high enough.

Hindmarsh Shire Council is now working to quantify the value of the regatta for the town, so that the full societal costs of the broken weir can be brought to light.

Local management of natural resources is often complex and this impacts on effective decision-making. The Dimboola Weir is owned by GWM Water (the local water authority). Decisions about how to operate the weir (e.g. adjusting water heights in the river) are made by the Wimmera Catchment Management Authority. The actual operation of the weir is undertaken by the Hindmarsh Shire Council. Importantly, though, it is the whole town and surrounding area that shares the socio-economic benefits of the weir and the ‘costs’ of its absence.

For all organisations, it is generally considered advisable to integrate climate change impacts into existing risk management frameworks, whether that is a physical risk or a purely financial risk such as that faced by investors.¹¹²

3.2 Climate change and the future of Victorian infrastructure

Who is Responsible?

The Dimboola Weir experience demonstrates that responsibility for dealing with the impacts of climate change on the built environment is the responsibility of a wide variety of people, not just the owners of property and infrastructure.

Stakeholders in any piece of infrastructure can include all levels of government, regulatory authorities, the insurance industry, engineers, lawyers, banks and lending institutions and others. Community members are also expressing their interest in local adaptation strategies and are insisting on being included in discussions and the development of solutions.

State and Federal Parliaments have a critical role, ensuring that the legislative framework governing our built environment is capable of allowing, and even promoting, the necessary innovation for adaptation actions.

The business sector is also key to adaptation. A recent review of global business attitudes found that 90% of businesses surveyed had been impacted by climate events in the past three years.¹¹⁰ The survey noted that, in response, approximately one third of businesses are taking a range of actions to address the coming impacts of climate change.

Adapting to climate change is also seen by some businesses as presenting opportunities, for example through providing products or services that would help others adapt. Specifically relating to infrastructure, 38% of businesses see adaptation as primarily an opportunity to climate-proof physical assets.¹¹¹

For all organisations, it is generally considered advisable to integrate climate change impacts into existing risk management frameworks, whether that is a physical risk or a purely financial risk such as that faced by investors.¹¹²

Flexibility and Efficiency

Difficult decisions lie ahead, with much complexity to consider. Figure 24 shows how decisions about infrastructure made today should consider a very different, future climate.

Uncertainty in the impacts of climate change, as in every other area where complex decisions are made, is an incentive for innovation and creativity.

In defence strategies such as the Defence White Paper,¹¹⁴ we do not pick one possible future scenario and plan for only that scenario. We do not assume that one particular country or terrorist group will be the only threat in the future, ignoring the possibility of others. Nor should we do so in the face of the uncertainties attending climate change. Interestingly, critical infrastructure planning for terrorist attacks on Sydney is now being deployed for climate change sea-level inundation eventualities.¹¹⁵

The UK Environment Agency developed the Thames Estuary 2100 project to deal with sea-level rise in London.¹¹⁶ This long-term risk management plan incorporates climate change projections in the design of a system of barriers to prevent flooding across London. Rather than assuming a specific increase in ocean levels, the planners have designed major infrastructure that is adaptable across a range of projected sea-level rise possibilities.

When adapting, it can be tempting to choose a particular future climate scenario and make the best decision under that scenario (referred to as an “optimal” decision). However, it is becoming increasingly important to re-think how we plan for climate change. Focussing on “optimal” outcomes could lead to maladaptation - misguided investments and infrastructure that is inadequate for mid-century climate conditions - if decisions are based on a specific climate future that does not eventuate.

“Robust” decisions - those that are least sensitive to future climate conditions, or that will be good decisions regardless of the extent of future changes in climate - make more sense strategically when faced with an uncertain future.¹¹⁷

Focussing on “optimal” outcomes could lead to maladaptation - misguided investments and infrastructure that is inadequate for mid-century climate conditions...

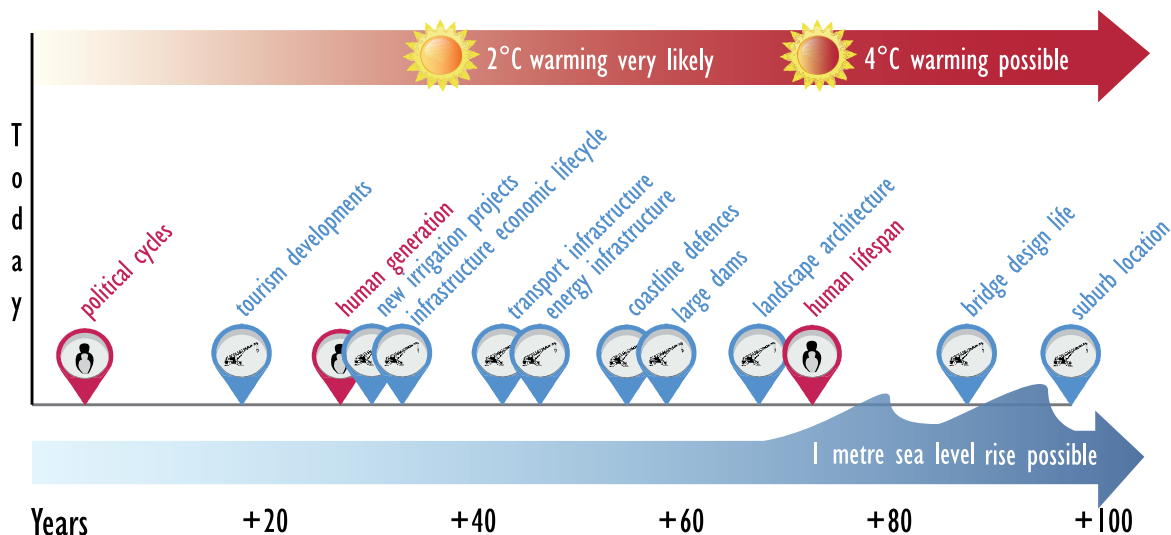


Figure 24:
Adapted by CfES from CSIRO.¹¹³



Photo: Elizabeth St in flood, March 2010 (from: <http://www.flickr.com/photos/gemmajones/4446963060/>)

3.3 Responding to the challenge

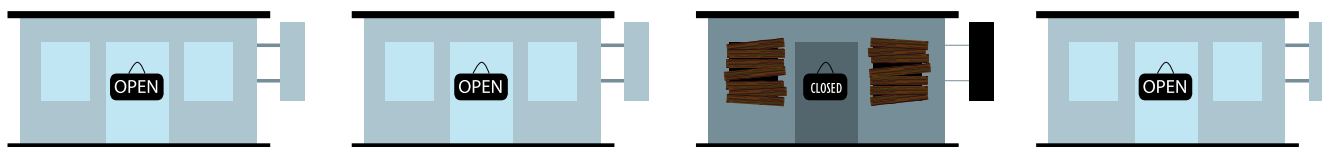
No-regret strategies

Recent developments such as green roofs and green walls (where vegetation is grown on a surface through a special soil-type substrate) also reduce electricity demand by providing insulation. Additionally, green roofs help reduce the urban heat island effect found in large cities (see Chapter 6). Perhaps their most valuable co-benefit, from the perspective of reducing the impacts to infrastructure, is their ability to capture rainfall, helping to reduce the amount of stormwater running into drains during heavy downpours, thus ameliorating the risk of flash flooding.¹¹⁸

Another method for combating flash flooding in heavily urbanised areas is the use of permeable pavement. Currently, hard surfaces like concrete, bitumen and other paved areas prevent rain from soaking through to the soil beneath, and instead funnel water towards drains. When drains overflow, there is nowhere else for the water to go, resulting in flash flooding.

Elizabeth Street in central Melbourne is built along an old creek bed and is often flooded during major rain events – most recently in 2010. It is the lowest point in the Melbourne CBD and largely surrounded by extensive areas of impervious surfaces. The City of Melbourne is in the process of implementing porous surfaces to reduce the damage caused by heavy rain. This work will be beneficial in today’s climate, and will continue to provide benefits in the future, as rainfall intensities are projected to increase by 30% by 2030.¹¹⁹

25%...



...of Melbourne CBD businesses don’t reopen after flood damage

Figure 25:
Closed Businesses.

CfES developed infographic.¹²⁰

Better design and insulation of buildings reduces the cost of heating and cooling, and thus can help reduce the strain on the electricity grid during times of peak demand. Innovative new buildings in Melbourne such as the City of Melbourne’s “Council House 2” and the award-winning Pixel Building both make use of “night-time purging” - a system whereby the warm air that has collected in the building during the day is vented to the night sky.¹²¹ In Council House 2, this system alone reduces the building’s daytime cooling requirements by 20%.¹²² Existing buildings can also be retrofitted for improved energy performance.

The Green Building Council of Australia and the Australian Green Infrastructure Council are both developing energy rating tools to help owners of buildings and other infrastructure reduce electricity demand.

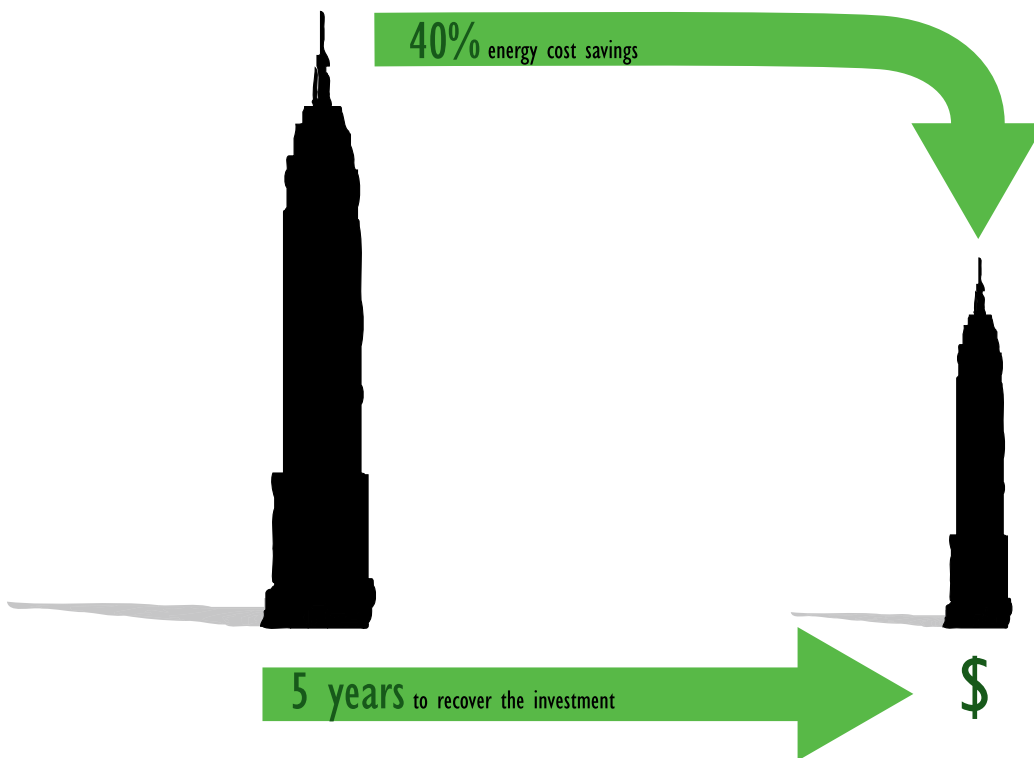


Figure 26:
Empire State Building
retrofit.¹²³

Safety-margin strategies

Where certain events can be anticipated, it is often beneficial to address them pre-emptively at the design stage, rather than to try to retro-fit or upgrade later.

HafenCity is a new suburb in the port area of Hamburg, Germany. Until recently, the site was essentially a disused port, but now it is home to 126 hectares of homes, businesses and public spaces. The developers designed the entire water-front suburb for resilience against significant sea level rise. Living, working and transport areas are elevated to avoid storm surges. Certain areas are explicitly designed to accommodate flooding, but in such a way that the operation of the suburb is largely unaffected.¹²⁴

Even where coastal defences or infrastructure is built, it is important to take adequate account of the scale of events these structures will need to withstand. The effect of Hurricane Katrina on New Orleans stands as an example of what can go wrong when man-made defences fail - vast tracts of the city were flooded and damaged, several hundred people died, and critical infrastructure such as electricity and water were disrupted. The longer-term impacts also must not be forgotten: on-going post-traumatic stress disorder, environmental damage and health problems from leaked oil, petrol and other chemicals, and regional economic impacts.



Photo: "Last House Standing" after Hurricane Ike, Source <http://news.blogs.cnn.com/2011/07/26/owners-of-last-house-standing-part-of-peninsulas-comeback>.

In 2008, Hurricane Ike devastated Cuba, Haiti and the USA's Gulf of Mexico coast. In the town of Gilchrist, Texas, the scene was one of utter devastation, with the exception of a single house (see photo). Built in the wake of Hurricane Rita, the "Last House Standing" was explicitly designed to withstand the future events it was likely to face. The higher construction standard may be moderately more expensive, but has meant this house survived where none others did.

Coastal risks

Some issues confronting coastal communities in relation to sea level rise are similar to those faced by communities living in peri-urban areas where the risk of bushfires is increasing. Both involve establishing the built environment in locations where natural hazards exist and where these hazards are projected to become worse with climate change.

In our state the *Victorian Coastal Strategy 2008* sets out the policy and strategic direction for responding to coastal hazard risks in the context of climate change. The strategy identifies the need to:

Plan for sea-level rise of not less than 0.8 metres by 2100, and allow for the combined effects of tides, storm surges, coastal processes and local conditions such as topography and geology when assessing risks and impacts associated with climate change.

In recognition of the long-term impacts of possible sea level rise, the State Planning Policy Framework of the *Victoria Planning Provisions* and local planning schemes reflect the Victorian Coastal Strategy, and the policy applies to non-urban land, greenfield land and development beyond existing settlements in coastal areas.

With regard to development proposals in existing settlements and urban zoned areas. The State Planning Policy Framework specifies:

*In planning for possible sea level rise, an increase of 0.2 metres over current 1 in 100 year flood levels by 2040 may be used for new development in close proximity to existing development (urban infill).*¹²⁵

The Commonwealth funded the *Climate Change Risks to Australia's Coast: a first pass national assessment* and the *Climate Change Risks to Coastal Buildings and Infrastructure - A Supplement to the First Pass National Assessment* and produced maps which the Department of Climate Change and Energy Efficiency describe as showing “low-lying vulnerable areas for a low (0.5m), medium (0.8m) and high (1.1m) sea level rise scenario, for the period around 2100”. This was done “to help understand the potential impacts and risk to society” and “help communicate the risks of climate change.”

The Australian Government has adopted a view that there are significant benefits for governments, businesses and communities in considering the adoption of a nationally consistent sea-level rise planning benchmark,^{vi} but a level has not been determined.

One difficulty of dealing with sea-level rise is that there is no one-size-fits-all solution. Outcomes in a given place depend heavily on local peculiarities. Flood mitigation infrastructure may not be suitable for all areas for reasons of cost and geography.¹²⁶ The issues are complex, requiring continuing careful consideration at all levels of government.

Soft strategies

Not all approaches to deal with the impacts of climate change on the built environment necessarily require construction-based solutions. There are many “soft” strategies that, in the right situations, can also provide flexible and robust pathways to change.

In Britain, organisations that manage major infrastructure are required by the UK *Climate Change Act* to develop plans to deal with the impacts of climate change. The list of organisations includes gas and electricity generators and suppliers, road and rail networks, ports, airports, water authorities and economic regulators (similar to our Essential Services Commission).¹²⁷ By requiring these plans, the UK is encouraging genuine long-term thinking and planning from organisations that control major infrastructure, with a view to ensuring future resilience to climate impacts.

One difficulty of dealing with sea-level rise is that there is no one-size-fits-all solution.

vi Australian Government response to the House of Representatives report—Managing our coastal zone in a changing climate

Similarly, insurance schemes provide incentives to appropriately consider future increased risks, but they are unlikely to be a panacea – as risks increase, so will insurance premiums, potentially making coverage unaffordable for many.

Early warning systems can also be effective at minimising loss and disruption from a wide range of extreme events - from heatwaves and bushfires to floods and storms. Providing information and notifications can help reduce the cascading losses from infrastructure failure.

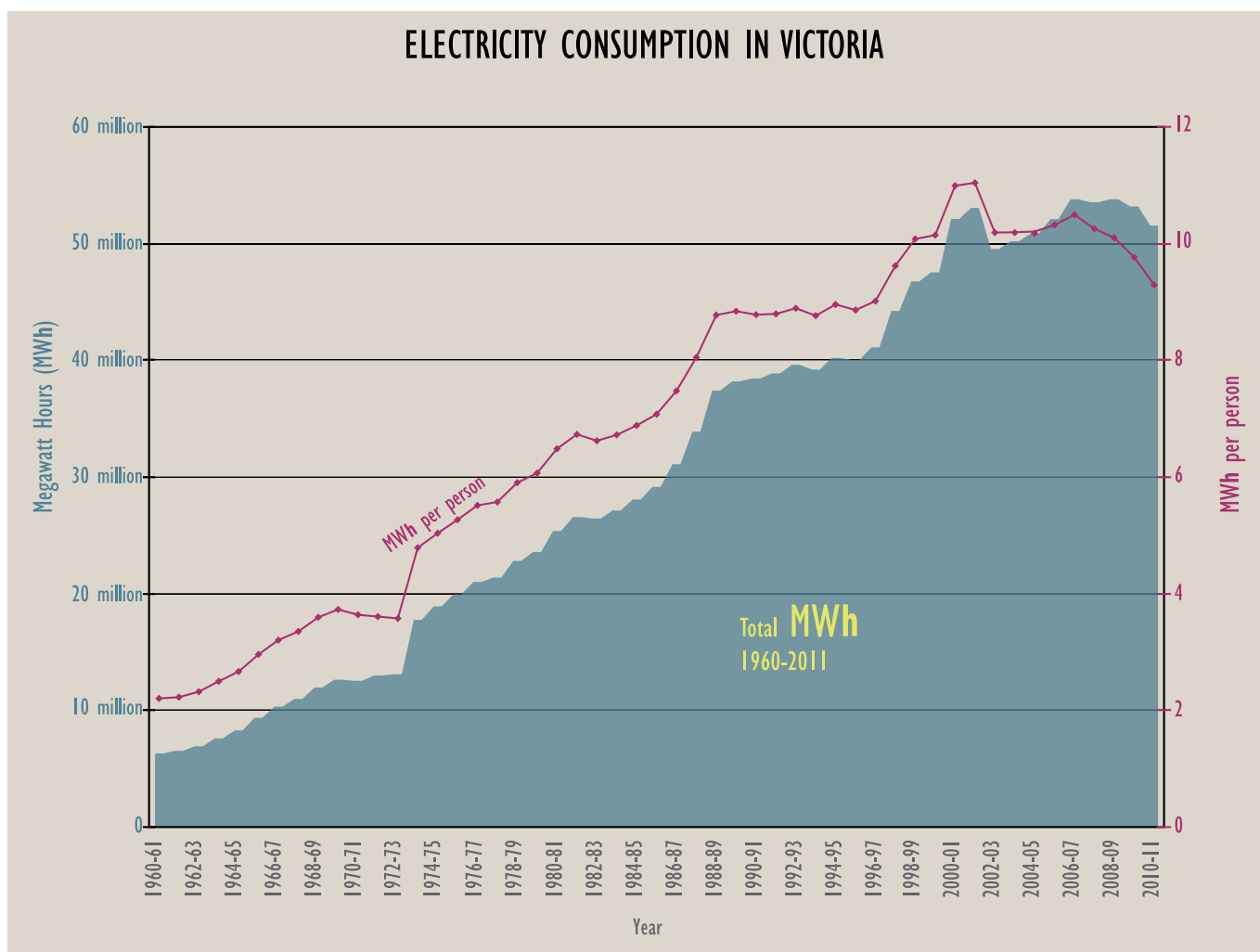
Reducing maximum demand for energy

One particularly important “soft strategy” (mitigation/adaptation) is managing how much electricity we use.

Our electricity consumption has increased almost ten-fold in the last 50 years (Figure 27). Factoring in population growth, the average person today still uses about five times as much electricity as a person in the 1960s.

Figure 27:
Electricity consumption in Victoria.

CfES developed infographic.¹²⁸



Air conditioners provide an illustration of maladaptation. While keeping us cool, they are increasing our emissions of greenhouse gases (Figures 28-29). Further, by placing extra strain on electricity supplies, particularly when the weather is hot, air conditioners also necessitate additional construction of infrastructure.

For every \$1500 air conditioner unit installed, approximately \$7000 needs to be spent on network upgrades – a cost that is shared across all users, regardless of air conditioner ownership.¹²⁹

Figure 28:
The influence of daily temperature on electricity demand.

Temperature data available from BoM¹³¹; electricity data available from Australian Energy Market Operator.¹³²

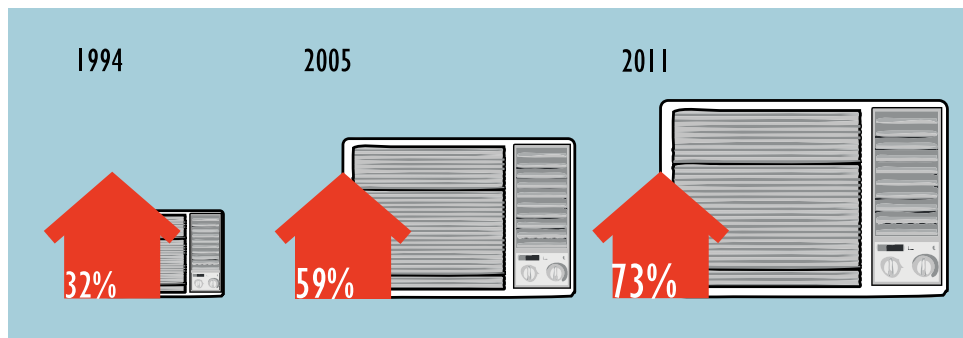
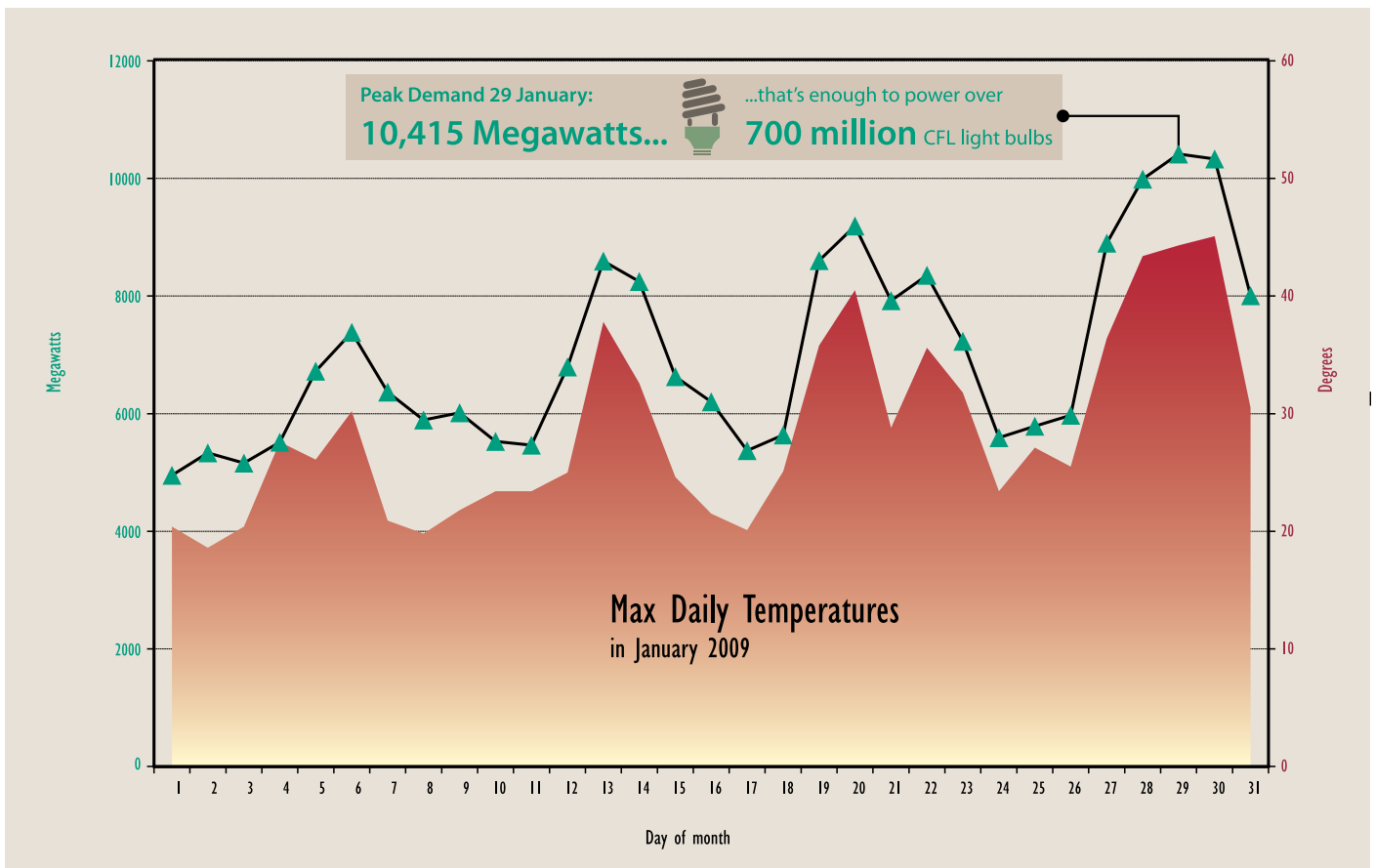


Figure 29:
Ownership of air conditioners.

Australian Bureau of Statistics data CfES developed infographic.¹³⁰

When consumers have access to real-time price information through smart meters and a tiered pricing system for peak and non-peak consumption, they will be able to make informed choices about their electricity use.

How much electricity we use is directly linked to the possibility of black-outs during heatwaves. Summer maximum demand in Victoria was projected to increase by 2-3% per year,¹³³ although there is now recognition that, for a variety of reasons, maximum demand may now not be rising that quickly. Hot days and higher temperatures lead to higher electricity demand, with daily maximum demand tied very closely to daily maximum temperatures.

With sufficient planning, some of the social consequences of blackouts could be minimised (see Chapter Six), even as the physical limitations of critical infrastructure cannot always be avoided (e.g. over-heating of machinery in water treatment plants).¹³⁴

The construction of additional electricity infrastructure (generation capacity, transmission lines, distribution networks) will continue to be deployed to combat rising maximum demand – this can potentially include distributed generation from renewable energy resources. The construction of this infrastructure is a key factor behind rises in electricity bills over the past decade. Higher infrastructure costs mean higher costs for consumers.

Without building more infrastructure, is it possible to avoid blackouts simply by managing summer maximum demand? Demand management may be a higher-risk strategy than building more or bigger cables, but it is much cheaper and potentially has other benefits including mitigation - reduced carbon emissions. The Commonwealth Energy White Paper (2012) urges adoption of this sort of strategy.

When consumers have access to real-time price information through smart meters and a tiered pricing system for peak and non-peak consumption, they will be able to make informed choices about their electricity use. Where price increases are used to decrease demand (or to shift demand to other times), equity issues need to be addressed so that the impact of heatwaves is not felt disproportionately by low-income households or those with unavoidable high daytime energy needs.¹³⁵

Arrangements have been made between electricity retailers and some large consumers of electricity. Under the agreements, the large users agree to shut down at times of peak demand to protect the network, in exchange for cheaper electricity at other times. A small number of users can release enough electricity to constitute the difference between a system under strain and a system unable to cope. Such schemes could also be extended to residential customers.

The existing regulatory framework for electricity enables the expansion of the generation network without any consideration of reducing demand¹³⁷ - despite the options available for demand-side management. On the back of public backlash over rising electricity prices, the last two years have seen a major shift in thinking in the energy sector on these regulations, which currently represent a barrier to effective adaptation. Competing interests between the various players in the energy sector has also been identified as hampering adaptation efforts.¹³⁸

Since the Australian Energy Regulator (AER) called for changes to the price-setting rules to reduce the incentive to build more energy infrastructure,¹³⁹ the Australian Energy Market Commission (AEMC) has been investigating ways in which demand management can be made more effective. The final AEMC report finds ample scope for improvement in demand management in the grid, and this coincides with a change to the National Electricity Rules that gives greater power to the AER to control network investment.¹⁴⁰

Given the additional benefits of reduced demand (i.e. cost savings and lower greenhouse gas emissions), these are welcome developments.

Considering change

Flexibility and robustness manifest themselves in a variety of ways depending on the setting. There is no one-size-fits-all approach to ensuring our complex built environment, in all its diversity, is resilient to impending changes.

What are we prepared to pay to protect? What are we prepared to give up? The realities of climate change have changed the status quo. As a community, we now must work for change. The examples outlined in this chapter raise compelling questions for consideration.

Flexibility and robustness manifest themselves in a variety of ways depending on the setting.

CHAPTER FOUR - DROUGHT, FLOOD AND CLIMATE CHANGE

This chapter does not explore inland water systems, urban water issues or the ecosystem services they provide. Those matters will be addressed in the *Biodiversity and Land Foundation Paper* and *Water Foundation Paper*

In February 2011, many people in northwest Victoria - coming out of a protracted drought and surrounded by floodwaters in towns and farms - were asking themselves whether the drought and floods were the direct consequence of climate change (see Figure 30).¹⁴¹

Victorians across the state were considering this question too - particularly in the light of the flooding in southern Queensland which took lives as well as property, prompted a Federal Government levy on the public to pay for the damage, and challenged insurance company policies and sympathies.

Australian climate scientists have been considering this same question.

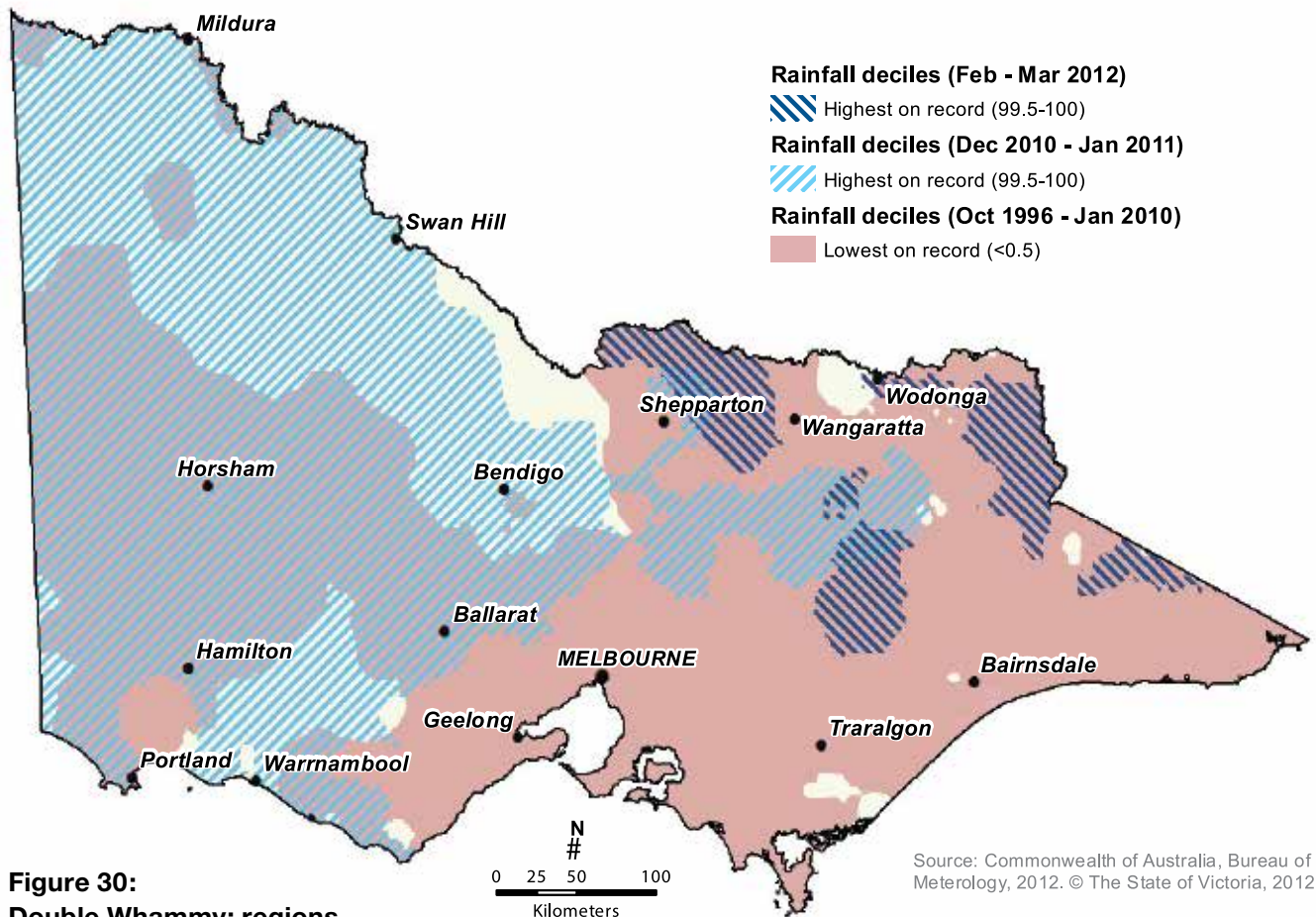


Figure 30:
Double Whammy: regions of Victoria impacted by the Millennium Drought (1996-2010) and the floods of Dec 2010 – Jan 2011 and Feb-Mar 2012.
 Source BoM data, map developed by Department of Sustainability and Environment for CfES.

The relationship between climate change, weather and extreme events is being examined around the world. Researchers in the UK have linked the millennium floods in England and Wales to anthropogenic climate change. There, flooding impacted 10,000 properties.¹⁴²

As Victoria, NSW and Queensland experienced record breaking rains in March 2012, the question continues to be asked.

In the case of drought, lower rainfall and reduced runoff in the south-east of Australia is in part due to natural variability as well as to human-induced climate change.¹⁴³

However, CSIRO's modelling¹⁴⁴ shows that the greenhouse gases we emit into the atmosphere are contributing to the atmospheric conditions necessary to increase temperatures and reduce rainfall.^{vii}

In terms of the recent flooding, the connection to anthropogenic climate change is more complex - it is difficult to attribute specific events to just climate change.

This is because each particular flood event is due to a combination of factors that operate over both short and long periods. Additionally a wide range of extreme events is a normal occurrence even in a stable climate.¹⁴⁵

What CSIRO can tell us is that recent flood events do reflect natural climate variability, but that the magnitude of such events over the longer term may increase with climate change.¹⁴⁶

“It is expected that long-term climate change will result in greater climate variability with more intense extreme events than in the past.”

CSIRO¹⁴⁷

Scientists reporting to the Intergovernmental Panel on Climate Change confidently state that human actions contribute to the “intensification of extreme precipitation at the global scale”.¹⁴⁸

As extreme drought and flood events become more frequent and severe, elevated levels of distress will be felt by Victorians across the State.

vii For a detailed description of these atmospheric drivers, see DPI's ClimateDogs: <http://www.dpi.vic.gov.au/agriculture/farming-management/weather-climate/understanding-weather-and-climate/climatedogs>

4.1 Climate change and a hotter, drier Victoria

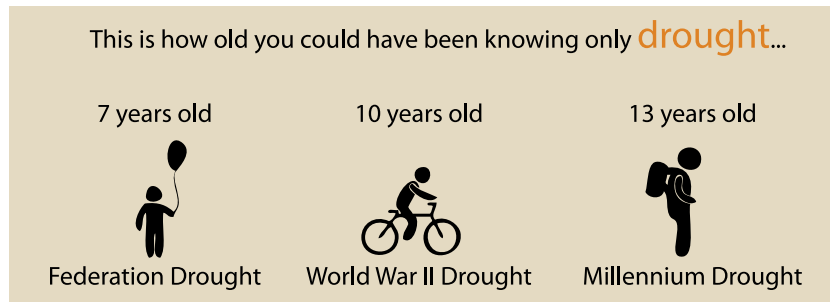
Our principal scientific agencies – CSIRO and BoM – demonstrate through evidence and modelling that the extremes we have seen recently are going to become more normal as drought and flood events become more frequent and extreme.

Victoria has a history of drought.

However, the recent drought, the “Big Dry” or the “Millennium Drought” was Victoria’s longest and driest ever. It lasted the greatest number of years, 14 in all, compared to 10 years and seven years for the other major droughts since records began (Figure 31).¹⁴⁹ It was also the driest, in that it did not have a single wet month; whereas the WWII drought had nine wet months during the 10 year drought.¹⁵⁰

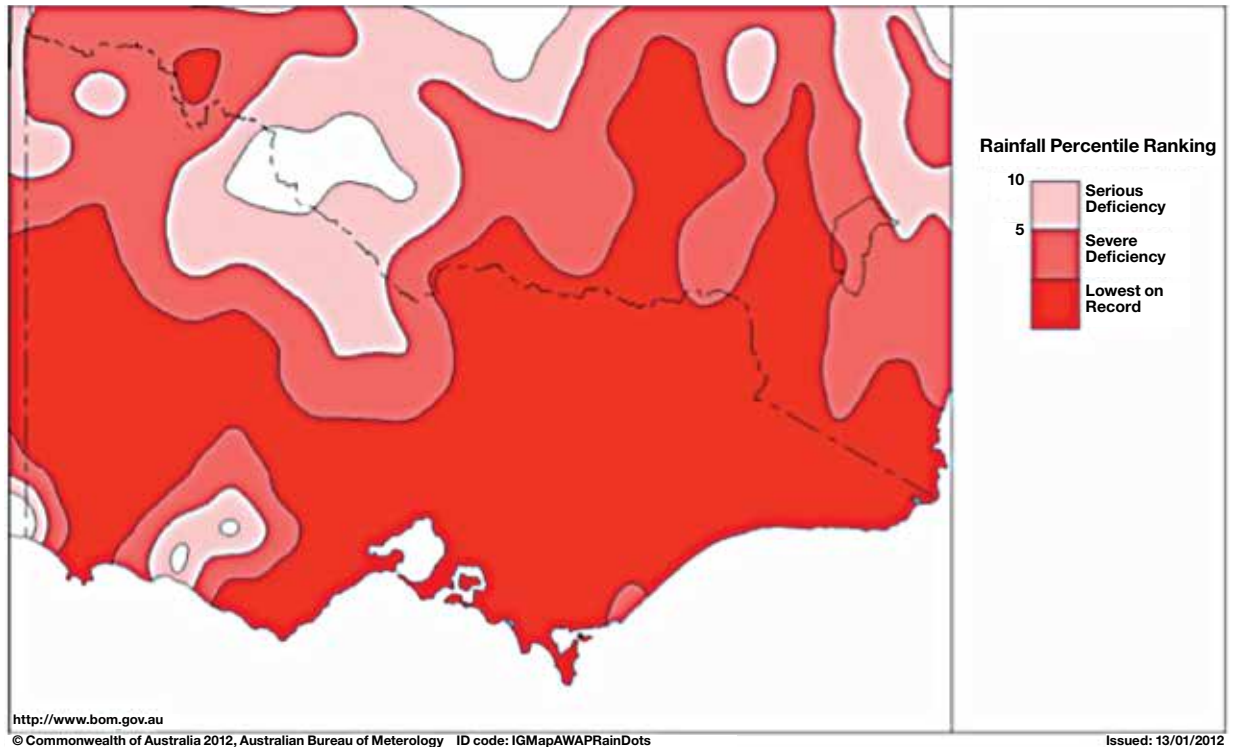
The Millennium Drought resulted in a reduction to Victoria’s average rainfall of around 15%.¹⁵¹

Figure 31:
Knowing only drought.
 CfES developed infographic¹⁵²



Most of Victoria experienced the lowest observed rainfall on record during this period (Figure 32).

Rain Deficiencies (AWAP LowRes 1900–now) 1 October 1996 to 31 January 2010
Distribution Based on Gridded Data
Product of the National Climate Centre



Importantly, projections indicate more extremely hot years and extremely dry years for Victoria in the future.¹⁵³ CSIRO projects that the extent and frequency of droughts in Victoria may more than double by 2050.¹⁵⁴ This will have serious impacts on Victorian landscapes and communities.

Direct Impacts of Drought

Natural environment

Self evidently reduced rainfall results in reduced water availability in rivers and streams on the surface, as well as groundwater storages. However, it also reduces the amount of moisture in the soil as natural evaporation is not replaced through rainfall.

Soil erosion and nutrient loss impact on the ability of plants to thrive, resulting in failing crops for farmers, and fewer sources of food and shelter for wildlife. Fish, platypus and other aquatic wildlife have less water in which to live, and the quality of the water that remains is reduced. This degraded habitat impacts on the ability to reproduce and survive.

Increased dryness also creates the conditions for more severe bushfires.

Figure 32:
Rain deficiencies during Millennium Drought.

Source BoM.

NB: Rainfall decile 1 means that the observed totals fall in the lowest 10% of historical totals for this length of period.

Agricultural productivity

Warmer and drier conditions will have a range of impacts, including lower crop quality, increased risk of disease and pests, and reduced yields.¹⁵⁵ Decreasing rainfall, increasing carbon dioxide levels and higher temperatures could decrease overall wheat quality in western Victoria by 34% by 2050.¹⁵⁶

Grazing industries (including livestock and dairy) will suffer from a decline in forage quality, thermal stress on livestock, and increased pests, diseases and weeds.

Urban water supply

Under drought conditions, water storages are not refilled, putting pressure on water supply for cities and towns as well as rural areas.

Regionally, for three consecutive seasons between 2006 and 2009, water was pumped from the Waranga Basin, near Rushworth and Tatura, below the normal off-take level, to supply water for irrigation. This had only occurred twice before, during extreme drought in 1926 and 2003.¹⁵⁷

As a result of record low inflows in 2006 and 2007, water entitlement holders on the Latrobe River System faced supply shortfalls. Gippsland Water, power generators and the Latrobe River irrigators were all looking to source additional water to cope with the impact of the unprecedented low inflows.¹⁵⁸

Goulburn Valley Water's Sunday Creek system supplies the towns of Kilmore, Broadford, Wandong, Heathcote Junction and the surrounding area. During 2007 and 2008, Goulburn Valley Water resorted to carting water from Seymour to supply Broadford, resulting in costs of more than \$2.5 million.¹⁵⁹

Water restrictions try to limit the consumption of water in urban areas to make existing storages last longer. In Victoria, permanent water saving rules came into place in 2005, mainly targeting outdoor uses. From September 2006 to September 2010, at least 200 towns were under water restrictions at any one time - up to over 450 towns at one stage.¹⁶⁰ Ballarat, for example, was subject to the harshest restrictions (Stage 4, which bans outdoor water use entirely) for almost three years.¹⁶¹

Indirect Impacts of Drought

Water scarcity and its consequences for agriculture, biodiversity, ecosystems and human settlements are clear. Not so apparent, however, are the flow-on effects of drought and their social and environmental implications.

Rural economic instability

Impacts on agricultural productivity means reduced revenue for farmers which can lead to community-wide financial hardship.

A 2008 study conducted by Department of Primary Industries, investigated the link between rainfall variability and agricultural production. The study found that variability of annual rainfall over the years on grain farms does have a medium to strong impact on the variability of farm business profit and cereal production, especially wheat production.¹⁶²

A 2011 study of the Wimmera-Mallee region supports this finding, as it showed a close relationship between growing season rainfall and wheat production (see Figure 33).

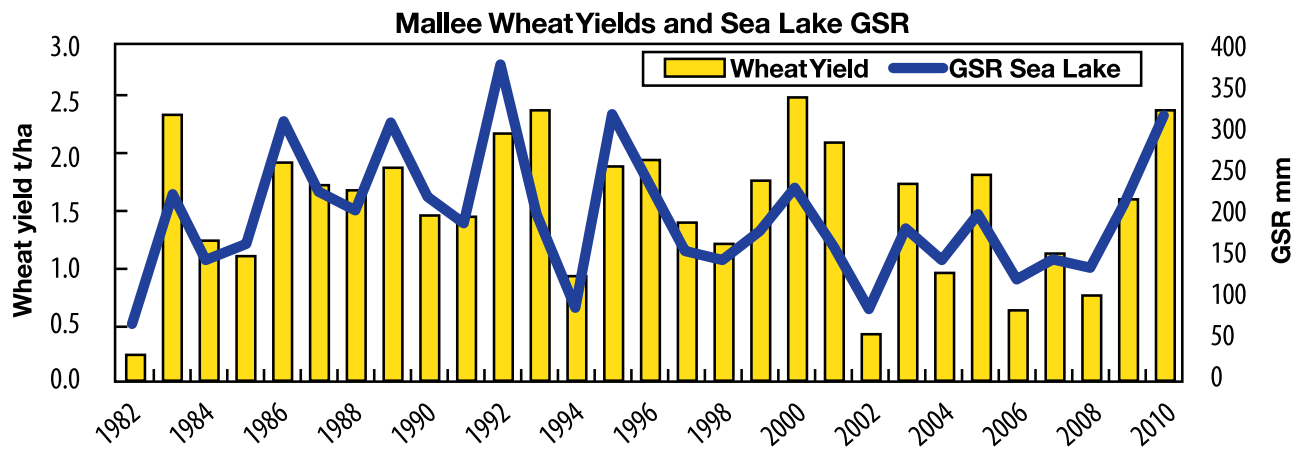


Figure 33: Mallee annual wheat yield and growing season rainfall for Sea Lake.¹⁶³

Financial hardship is more common in drought affected areas.

The study further found that farmers in the region also experienced increased ratios of debt to equity as a result of greater borrowings required to cover cash deficits during the dry years.¹⁶⁴ This is no surprise to farming communities.

Financial hardship is more common in drought affected areas. A recent study found 47% of farmers living in a drought-affected area were experiencing financial hardship, whereas only 25% of farmers who had not experienced drought in the last three years were in the same situation.¹⁶⁵

During drought, farmers also fare worse than their community neighbours. A study by the Australian Institute for Family Studies (2008) revealed that a much higher percentage of farmers were in financial hardship than people who are employed but not in agriculture.¹⁶⁶

Australia is not the only country whose agricultural industries are experiencing record-breaking droughts due to climate change. In 2011, a drought in Texas resulted in record \$5.2 billion in agricultural losses, making it the USA's most costly drought on record.¹⁶⁷

Buying the essentials

Lost productivity in the agricultural sector has impacts on everyone through an increase in food prices, which can hit families on a tight budget the hardest.

In the two years from September 2005 to September 2007, food prices in Australia increased at *twice* the rate of the Consumer Price Index.¹⁶⁸

In 2007, the ANZ Bank identified the drought as a primary contributor to these soaring food prices, where the average Australian grocery bill rose 12%.¹⁶⁹ The availability and affordability of nutritious food is critical to maintaining a healthy society and food independence. More frequent and severe drought is likely to make it harder to get local, affordable food.

These increases in prices of essential commodities affect everyone; however those on lower incomes are more likely to struggle as food and water take up more of their weekly budget.¹⁷⁰ These burdens are in addition to the potential rises in energy costs outlined in the preceding chapter.

This raises concerns over fair and equal access to the basics which become less affordable for society's most vulnerable groups.

Reduced amenity and recreation

Water restrictions reduce the health and vitality of home gardens and public spaces. These parks and green spaces are valued by the public for urban amenity, such as recreation, youth development, and social capital.¹⁷¹

In particular, reduced water availability for sporting fields and other spaces reduces opportunity for physical activity and social cohesion such as community convergence, local identity and pride, and economic activity are all effected.¹⁷²

As discussed in the previous chapter, Dimboola Rowing Club was unable to hold its annual regatta due to lack of water in Lake Dimboola in 2010, which impacted on local tourism, social networks and recreation in the town. Lake Wendouree suffered similarly, as well as countless footy grounds, cricket grounds, and other sporting and recreation spaces across Victoria. This reduction in recreational and community capacity is difficult to measure, but there is little doubt it will worsen under a drier climate.

Mental illness and depression

Australia's National Rural Health Alliance points to the presence of a causal relationship between drought-related trauma and individuals at-risk in agricultural communities.

A 2007 report by the *Australian Institute for Health and Welfare* showed that 15–24 year-old males in regional areas are 1.5–1.8 times more likely to commit suicide than their urban counterparts. The incidence is up to six times higher in very remote areas, due to a number of factors including unemployment, lack of access to mental health services, and migration of peers to urban areas.¹⁷³

According to a 2011 report by the *Climate Institute* - financial strain, landscape degradation and a dwindling rural population are all factors that raise the risk of suicide among older, male farmers, and all are set to increase under climate change scenarios.¹⁷⁴

Australia has relatively high carbon emissions compared to other industrialised economies because of our high reliance on coal.¹⁷⁹

Cascading Impacts of Drought

Although we cannot be certain of the intensity and frequency of future droughts, social and economic studies provide insights into the longer-term and ongoing challenges of a hotter, drier Victoria.

Decline of rural communities

Drought areas have been associated with lower employment rates.

Since 1996, entry of young persons into farming in Australia has continued at low levels following a sharp decline in the 70s and 80s.¹⁷⁵ As older farmers exit the industry, fewer young farmers are taking over. Remote areas, such as the Mallee and Wimmera, where agriculture will need to adjust to climactic change, are in decline and becoming increasingly isolated from health and community services, and educational and economic opportunities.¹⁷⁶

Rural communities often depend on farming and farm income to drive other economic and social aspects of their community, and productivity downturns mean less economic activity, fewer jobs, and fewer people in towns. Although drought cannot be directly attributed to migration from rural areas at this time it is an additional pressure on towns already experiencing decline and isolation.¹⁷⁷

Energy, water and carbon emissions

Water availability has a close relationship with another important aspect of our lives – energy. Stationary energy is a significant water user, consuming about 4% of non-agricultural water.¹⁷⁸ Higher water prices mean that energy could become more expensive as costs to supply energy to power stations increases.

New water supply infrastructure requires substantial amounts of energy. Desalination plants, pumps for pipelines and water recycling stations all require significant resources of energy.

This poses a critical feedback loop where rising energy costs compound the expense of water supply which in turn puts additional pressure on the price of energy.

The consequences are not only economic.

In order to adapt to a drier climate which is being driven by human emissions, we will need to generate more water for human and natural uses to compensate for lower rainfall. However, the energy needed to produce this water actually *uses* lots of water and emits greenhouse gases that are driving the drier climate in the first place.¹⁷⁹

Restrictions and water efficiency measures would appear to be a preferable alternative to more infrastructure which drives up prices, emissions, and water use simultaneously.

4.2 Climate change and an increase in more extreme rainfall events

In stark contrast to 1997-2009, 2010 was the fifth wettest year on record in Victoria and the summer of 2010-11 was the wettest in Victoria since records began, with several rivers experiencing the largest or second largest flood ever recorded.¹⁸⁰

The rainfall in early 2012 was also record breaking, with the highest observed rainfall at many points across the state. The north-east in particular was affected (see Figure 35). CSIRO tells us that a warming climate is likely to result in more extreme rainfall events and this could potentially result in more severe flooding.¹⁸¹

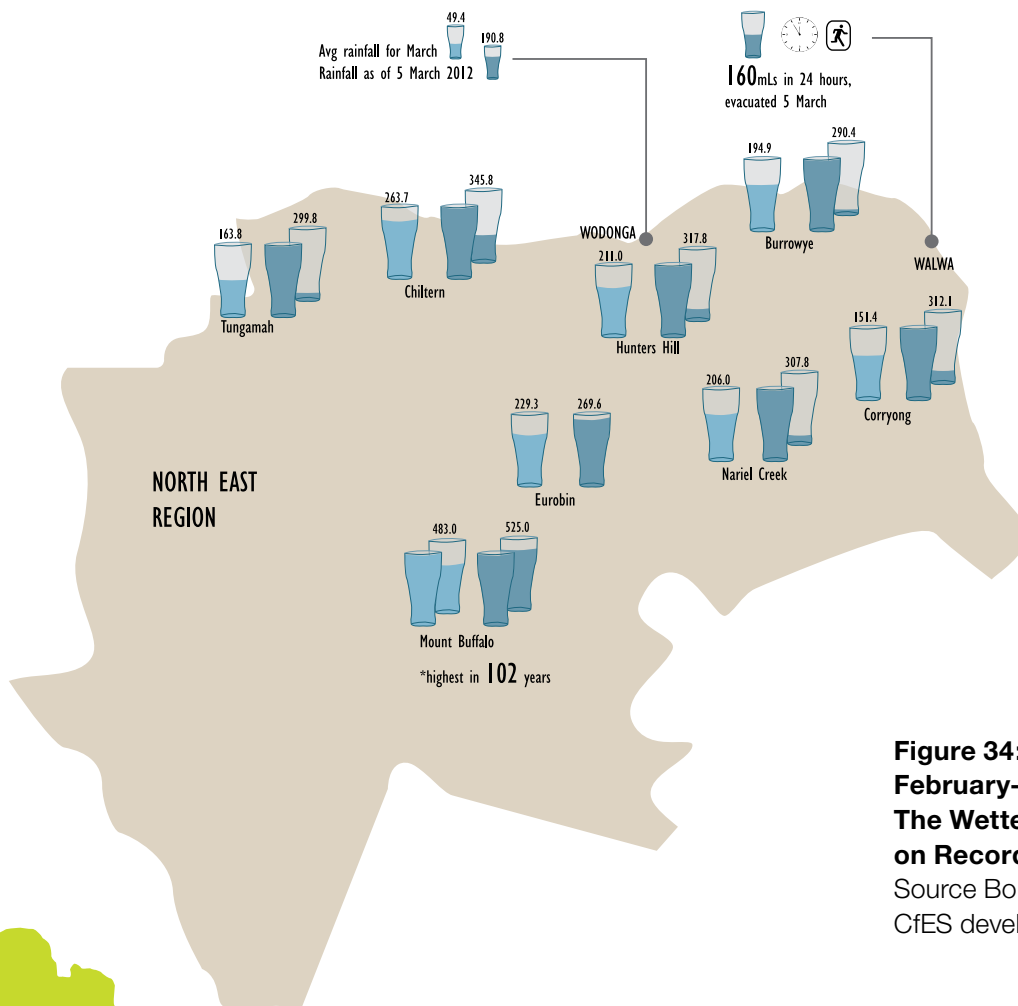
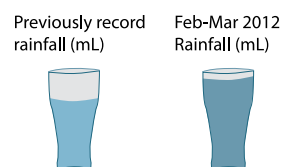


Figure 34:
February-March 2012:
The Wettest 7-day Period
on Record.

Source BoM.

CfES developed infographic.



Victoria and the La Niña Event

The wet summers we have experienced recently are partly due to the close relationship between the La Niña weather phenomenon and rainfall in Australia, and a potential connection between the strength of La Niña and changes to sea surface temperatures.¹⁸²

Australia is more likely to get flooding during strong La Niña events because of the unseasonably heavy rains that accompany La Niña. The flooding events of 1950, 1974, 2010-11 and 2012 all occurred in a strong La Niña period.¹⁸³

Although La Niña is a naturally occurring event, there is now evidence to suggest that it may be strengthened by the rising sea surface temperatures associated with climate change.¹⁸⁴ If this is the case, it is no coincidence that ocean temperatures around Australia were warmer in 2010-11 than for any previous La Niña event.¹⁸⁵

Recent Flood Reviews

Two critical reviews of the 2010-11 floods have recently been released in Queensland and Victoria - the *Queensland Floods Commission of Inquiry Final Report*, March 2012 and the *Review of the 2010-11 Flood Warnings and Response* (Comrie Review), December 2011.

The Environment and Natural Resources Committee of the Victorian Parliament tabled its report on matters relating to flood mitigation infrastructure in Victoria on 29 August 2012.

Comrie Review and the Queensland Floods Inquiry

The Queensland Floods Inquiry's terms of reference extended beyond flood warnings and response, however its findings on the subject are consistent with those in the Comrie Review.

Recommendations in both reports include improving the understanding of roles and responsibilities of various agencies, as well as clarifying what directive powers emergency management staff (such as State Emergency Service) have during the emergency, and better overall communications.

The Comrie Review recommendations broadly support the Victorian Government's Green Paper on emergency management, *Towards a More Disaster Resilient and Safer Victoria*, and the companion document, *Victoria Prepared: An Action Plan*.

As the Queensland Flood Inquiry had broader terms of reference, some additional detail is provided below.

Emphasis on mapping

The Queensland Flood Inquiry had a particular and consistent emphasis on mapping as a highly desirable and effective flood management and planning tool. It gave numerous examples of councils who already use maps extensively, such as Brisbane and Ipswich, which make available, free of charge, property-scale flood reports to the public. This was considered best practice, and the Comrie Review recommended that all flood mapping commissioned or adopted by government be made available to the public, together with guidance on interpretation.

This emphasis on the role of quality mapping informing robust decision-making and better preparedness was also expressed in the Victorian Bushfires Royal Commission into the Black Saturday fires (see Chapter Five).



Support for buy-backs

The Queensland Government does not currently operate a state administered buy-back program for properties at high risk of flooding, although some properties were acquired through joint State/ Commonwealth programs on an ad hoc basis.

The Queensland Flood Inquiry recommends that councils consider implementing property buy-back programs as part of a broader floodplain management strategy (Recommendation 11.1). The Land Swap program and Grantham Development Scheme were used as exemplars in the Review due to the social cohesion benefits of relocating an entire community rather than individuals.

Performance of private insurers

The Comrie Review includes an analysis of the response times of each of the eight major insurance providers involved for assessing claims, making payments, and responding to appeals.

The Queensland Flood Inquiry received a limited number of responses from the public around insurance issues, potentially due to the necessary preoccupation of policy-holders with recovering from the effects of the floods, and their potential disinclination to re-live their experience through making submissions or providing evidence to the inquiry.¹⁸⁶

Impacts of Flood in Victoria

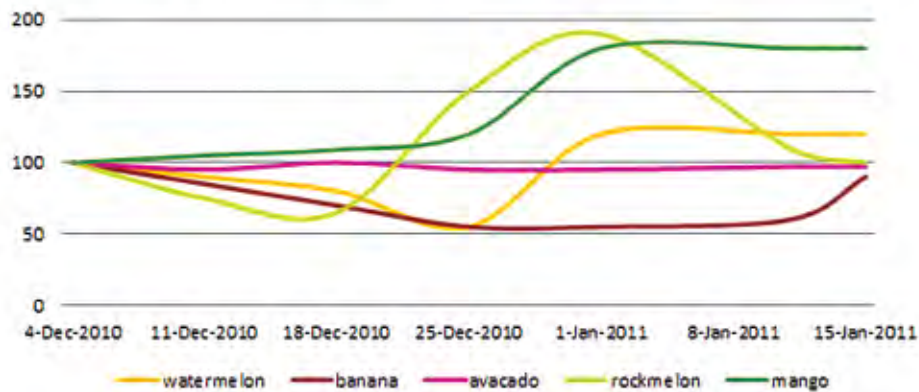
Commodity prices

According to ABARES, the impact of the 2010-11 floods on Australia's agricultural production and exports was roughly \$2.3 billion.¹⁸⁷

The flooded regions of Victoria accounted for around 19% of Australian milk production, 3% of vegetable production, and 13% of fruit production.¹⁸⁸ Flooding here and elsewhere in the country caused a sudden surge in food prices, particularly for fruits and vegetables from the affected areas. Melbourne shoppers felt the shock of flooding in the Gascoyne region of Western Australia in the price of mangoes, and the flooding in Queensland in the prices of zucchini and bananas (see Figure 35).

The flooded regions of Victoria accounted for around 19% of Australian milk production, 3% of vegetable production, and 13% of fruit production.¹⁸⁸

Weekly wholesale prices for selected fruit, Melbourne market



Weekly wholesale prices for selected vegetables, Melbourne market

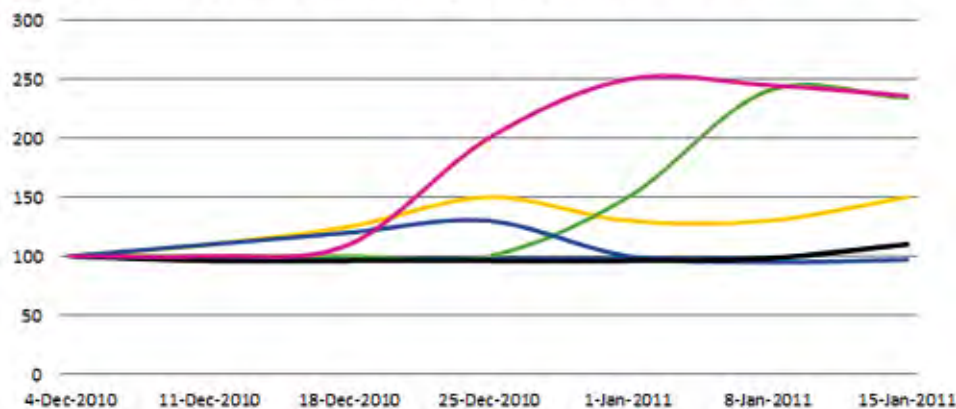


Figure 35:
Weekly wholesale fruit and vegetables prices, Melbourne market.
Source ABARES 2011.

Scarcity of supply was not only due to flood damaged crops, but also due to flood damaged infrastructure, such as rail and roads, which producers rely on to get their food to market.

Wheat prices also soared due to reduced supply, with winter wheat jumping to a two-year high.¹⁸⁹ The Australian cotton industry experienced 894,000 tonnes of projected losses driving up the price of cotton.¹⁹⁰ Australian sugar production in 2010–11 was 3.6 million tonnes, the lowest since 1991-92.¹⁹¹

High prices were welcome for some producers, who had managed to get their crops harvested in time and benefit from a bumper year. However the financial benefits for some are anticipated to be nowhere near enough to offset the overall economic fallout from the year's La Niña weather events, estimated at \$6 billion.¹⁹²

Scarcity of supply was not only due to flood damaged crops, but also due to flood damaged infrastructure, such as rail and roads, which producers rely on to get their food to market. These logistical delays can also serve to drive up prices, as commodities are trapped in production zones and out of reach of consumers. Fortunately, where transportation issues drive up prices, eventually the commodities are delivered and markets stabilise.¹⁹³

Financial Hardship and the Limits of Private Insurance

Many families and communities are trying to manage the risk of climate events through private insurance coverage. The recent floods in Queensland and Victoria exposed some serious gaps in flood insurance measures.

The *Queensland Floods Commission of Inquiry 2012* (see boxed text page 95–96) considered the role of the eight major insurance companies. Accepted claims far outnumbered declined claims, with roughly 73% of claims accepted and only 27% of claims declined.¹⁹⁴ However, the Commission's terms of reference "did not extend to what has emerged as the major complaint: the fact that many people thought they were insured for flood, but have found that the wording of their policies actually excludes their claims".¹⁹⁵

The *Natural Disaster Insurance Review 2011* addressed this issue.¹⁹⁶ The *Review* included the announcement of a new policy requiring all home insurance policies to include flood cover. The *Review* found that many Australians were "under-covered" in relation to flooding as current policies allow buyers to opt out of this type of cover, while they are not able to opt out of coverage for similar events - such as bushfire, storm and earthquake.

The new measures attempt to remove inequalities between providers by providing a standard definition of flood that applies to all insurance companies.

Cost of Natural Disasters - Victoria

The cost and expenditure relating to natural disasters is significant and wide reaching. The majority of cost analysis and data on the cost of disasters comes from the insurance industry, however using this data

as a basis of analysis is narrow as most identified costs refer to insured losses, which only includes a fraction of total costs of each event. Insured loss is usually associated with a small range of property and assets from 25-35% for severe fires and storms and only 10% for floods.

In order to provide a relatively standardised and comparative assessment of the cost of natural disasters to government, the figures presented below are based on information and data available from Australian Government Disaster Assist on funds provided in the recovery/relief cycle of a disaster. These amounts stem from payments made under the Australian Government Disaster Recovery Payment.

**Figure 36:
Cost of Natural Disasters
Victoria 2009/12.¹⁹⁷**

Costs Victoria 2009-2012 (Recovery/Relief)		
Disaster/Event	Disaster Assist payments	Insurance council estimates
<i>Victoria Severe Storms and Floods commencing 26 February 2012</i> (4,010 claims North/Central)	\$4,560,600	\$418,670,000
<i>Victoria Severe Weather Melbourne 25 December 2011</i> (North/Central)	Not disclosed	\$680,724,000
<i>Victoria Storms and Flash Flooding 18 December 2011</i> (North/Central)	Not disclosed	
<i>Victoria Storms 9-10 November 2011</i> (North/Central)	Not disclosed	\$122,465,000
<i>Gippsland Flood July and August 2011</i> (North/Gippsland)		
<i>Victoria Floods 22-23 March 2011</i> (North/Gippsland)	Not disclosed	
<i>Victorian Floods February 2011</i> (North/Central/East)		
Australian Government Disaster Recovery Payment (34,309 claims)	\$39,521,000	
Disaster Income Recovery Subsidy (1421 claims)	\$2,320,190	
<i>Victorian Floods January 2011</i> (North/Central/East)		
Australian Government Disaster Recovery Payment (34,309 claims)	\$39,521,000	\$122,465,000
Disaster Income Recovery Subsidy (1421 claims)	\$2,320,190	
<i>Victorian Floods September 2010</i> (North/Central/East)	Not disclosed	
<i>2009 Victorian Bushfires January-February</i>		\$1,100,000,000
Recovery Assistance Package	\$465,000,000	
Individual Assistance	\$82,000,000	
Income Recovery Subsidy for Employers	Not disclosed	
Assistance for Funeral/Memorial and Related Costs	\$850,000	
Caring for our Country Bushfire Recovery Program	\$10,500,000	
Total disclosed payments	\$646,592,980	\$2,444,324,000

Cost per-capita



Figure 37:
Cost of Natural Disasters
Victoria per-capita.
 CfES developed
 infographic.¹⁹⁸

1999/2001 – \$23
2009/2012 – \$118

As the scientific evidence linking climate change to extreme events is mounting and the likelihood of increased frequency and severity of bushfires, drought and floods is increasing, analysis of the rising costs of relief and recovery tells a compelling story (Figures 36-37).

The critical issues to note here are that although the figures are considerable – \$3.1 billion for the events from January 2009 to February 2012 – they are incomplete costs. The insured loss figures are associated with approximately 25-35% of property and assets damaged or lost in severe fires and 10% for floods.

The costs per capita to finance disaster recovery have risen from \$23 to \$118 in the past decade. However, this figure is narrow and does not incorporate the loss of social and environmental services.

In May 2012 Queensland’s biggest insurer Suncorp announced that the cost of premiums would rise dramatically and that it would no longer offer new flood policies in the towns of Roma and Emerald until levees were built. The Local Government Association of Queensland has responded by calling on the large insurers to contribute to the cost of flood mitigation works to take the pressure off governments.¹⁹⁹

This is an example of the emerging tensions as industry, government and communities tackle the increased frequency and severity of extreme events.

In the following chapter we will consider the risk of bushfire in more detail but it is critical to note that these figures further emphasise the point that will be made in the bushfire chapter – that it is critical to focus more energy and resources on preparedness as our exposure to extreme events increases in a time of climate change.

Former Federal Attorney-General Robert McClelland has described how little Australia spends on disaster prevention as “absolutely shameful”, compared with the billions spent on national security and the cost of recovery.²⁰⁰

Former Federal Attorney-General Robert McClelland has described how little Australia spends on disaster prevention as “absolutely shameful”, compared with the billions spent on national security and the cost of recovery.²⁰⁰

CHAPTER FIVE - BUSHFIRES

5.1 Bushfires in the landscape

Our recent history

During the Black Saturday bushfires one hundred and seventy three people died. Over 2,000 homes were destroyed and 430,000 hectares burnt. In addition, in the week preceding the fires, three hundred and seventy four people had their deaths hastened by the extreme heat events which reduced human resilience and turned a broad swathe of the environment into a tinderbox.

These personal tragedies and impacts are extreme, even given our history of exposure to bushfire events.

The Victorian Bushfires Royal Commission, 2009 (VBCR) led to a set of extensive recommendations and triggered major changes in how bushfire responses are planned and response managed. There were also changes introduced to strengthen the consideration of bushfire at different stages of the land use planning process and to better integrate the planning and building systems.

It is important to consider how these events and the phenomena of climate change are linked - to learn from those tragic events. CSIRO *State of the Climate* 2012 builds on the bushfire exposure knowledge in its *State of the Climate* 2010. We are now armed with two authoritative outlines of the climate science as it applies to us in this region. We have also seen in Chapter One of this paper, that notwithstanding the diversion of La Niña events we can only, realistically, expect the trend of increased temperatures to continue, persistent dry spells to test us, and bushfire vulnerability to continue and elevate (Figure 39).

The planet is warming, the climate is changing and Australia is vulnerable. Events that were once worst-case scenarios will become more likely. Governments will face the challenge of identifying areas and factors of extreme risk – both now and in the future - and adapt policy and practical responses to address these risks.

In the wake of the 2009 fires we, as a community, need to better reconcile human reactions and lifestyle choices with developing methods of dealing with forest ecological and climatic patterns. Long term retreat or transition options can be very sensitive matters for communities who might see these approaches as threatening their traditions and choices. Although future projected risks can be hard to visualise, the consequences, for example, of relocation a town, are not.

During the Black Saturday bushfires one hundred and seventy three people died. Over 2,000 homes were destroyed and 430,000 hectares burnt.

CHAPTER FIVE - BUSHFIRES

5.1 Bushfires in the landscape

Our recent history

During the Black Saturday bushfires one hundred and seventy three people died. Over 2,000 homes were destroyed and 430,000 hectares burnt. In addition, in the week preceding the fires, three hundred and seventy four people had their deaths hastened by the extreme heat events which reduced human resilience and turned a broad swathe of the environment into a tinderbox.

These personal tragedies and impacts are extreme, even given our history of exposure to bushfire events.

The Victorian Bushfires Royal Commission, 2009 (VBCR) led to a set of extensive recommendations and triggered major changes in how bushfire responses are planned and response managed. There were also changes introduced to strengthen the consideration of bushfire at different stages of the land use planning process and to better integrate the planning and building systems.

It is important to consider how these events and the phenomena of climate change are linked - to learn from those tragic events. CSIRO *State of the Climate* 2012 builds on the bushfire exposure knowledge in its *State of the Climate* 2010. We are now armed with two authoritative outlines of the climate science as it applies to us in this region. We have also seen in Chapter One of this paper, that notwithstanding the diversion of La Niña events we can only, realistically, expect the trend of increased temperatures to continue, persistent dry spells to test us, and bushfire vulnerability to continue and elevate (Figure 39).

The planet is warming, the climate is changing and Australia is vulnerable. Events that were once worst-case scenarios will become more likely. Governments will face the challenge of identifying areas and factors of extreme risk – both now and in the future - and adapt policy and practical responses to address these risks.

In the wake of the 2009 fires we, as a community, need to better reconcile human reactions and lifestyle choices with developing methods of dealing with forest ecological and climatic patterns. Long term retreat or transition options can be very sensitive matters for communities who might see these approaches as threatening their traditions and choices. Although future projected risks can be hard to visualise, the consequences, for example, of relocation a town, are not.

During the Black Saturday bushfires one hundred and seventy three people died. Over 2,000 homes were destroyed and 430,000 hectares burnt.

The Victorian Government has taken steps to improve emergency service delivery, improve our ability to respond to large-scale events and to implement the recommendations from the VBRC.

As people choose to live in fire prone areas, there needs to be a greater emphasis on personal responsibility in preparedness for fires. This imperative was acknowledged by the VBRC which reported that alongside the responsibilities of all tiers of government, “communities, individuals and households need to take greater responsibility for their own safety and to act on advice and other cues given to them before and on the day of a bushfire.”²⁰¹

Work has been undertaken in Victoria to address issues raised by the VBRC. The Victorian Government has taken steps to improve emergency service delivery, improve our ability to respond to large-scale events and to implement the recommendations from the VBRC. This includes the release in 2011 of, *Victoria Prepared: An Action Plan*, as a companion document to the *Green Paper on Emergency Management*.

Feedback on the *Green Paper*, along with the final report of the *Comri Review of the 2010-11 Flood Warnings and Response* (Victorian Floods Review), informed the development of a comprehensive policy proposal to reform Victoria’s emergency management arrangements. The Victorian Government has indicated its commitment to improving the state’s capacity to deal with and respond to natural disasters in the future.²⁰²

In December 2012 the Victorian Government released the *Emergency Management White Paper*, which sets out reforms for the emergency management in the state.^{viii} The reforms are intended to move the sector towards an all-hazards, all agencies approach and improve emergency management, with a strong emphasis on risk mitigation. The changes include the following:

- A new overarching emergency management body, Emergency Management Victoria, which will make sure agencies and departments plan and work together as well as share resources before, during and after an emergency. For the first time, one agency will oversee response and management for natural disasters and emergencies from preparation right through to community recovery
- The creation of an Emergency Management Commissioner, who will assume the operational responsibilities of the current Fire Services Commissioner and oversee control arrangements for fire, flood and other emergencies
- The establishment of a State Crisis and Resilience Council as the government’s peak body responsible for developing and coordinating emergency management policy and strategy and overseeing its implementation
- Reducing more than forty government committees involved in emergency management down to four
- A volunteer consultative committee called the Volunteer Consultative Forum to give volunteers direct input into the reform process
- The statutory role of Inspector General for Emergency Management will be established to review and monitor performance of Victoria’s emergency management arrangements.

viii <http://www.premier.vic.gov.au/media-centre/media-releases/5633-coalition-government-unveils-vision-for-emergency-management.html> <<http://www.premier.vic.gov.au/media-centre/media-releases/5633-coalition-government-unveils-vision-for-emergency-management.html>



BUSHFIRES

IMPACT

INDIVIDUALS & COMMUNITIES

Injuries
Fatalities
Loss of residence
Loss of cultural heritage

Stress
Grief
Social isolation
Domestic violence
health effects

BUSINESS & TOURISM

Loss of property
Discouraged tourism

Loss of business income
Stress

PRIMARY PRODUCTIVITY

Loss of timber
Loss of livestock
Loss of fencing
Smoke taint

Loss of income
Stress

ENVIRONMENT

Smoke
Reduced vegetation cover
Soil erosion

Loss of biodiversity
Reduced water quality
Reduced air quality

Health effects.
After the 2003 Alpine Fires the town of Wangaratta needed to introduce Stage 4 water restrictions to ensure a reliable supply of potable water.



Smoke taint.
The estimated value of wine producing grapes lost to smoke taint after the 2006-7 Great Divide Fires was \$15-20 million.



CLIMATE CHANGE & FIRE WEATHER



DROUGHT



Lower rainfall



Longer drought



TEMPERATURE



Increasing temperatures & greater extremes of temperature



WIND

Uncertain



HUMIDITY

Reduced humidity

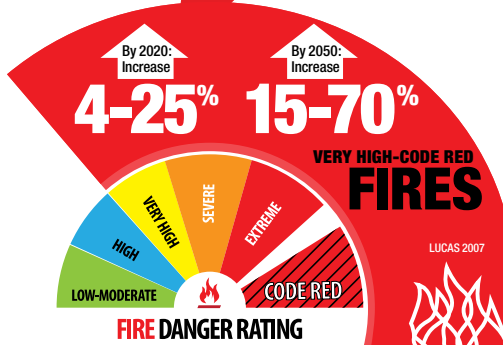


Figure 38:
Climate change increases bushfire occurrence and severity.

Source IPCC, Bushfire CRC, CFA and CSIRO. CfES developed infographic.

Rising temperatures, decreased water availability and increased atmospheric CO₂ may be working in opposite directions to influence fuel growth depending on local climate and dominant plant species.

Fire ecology

Managing fire in our ecosystems is not easy.

Bushfire is a natural phenomenon that plays an essential role in the ecology of the continent, causing profuse germination and flowering by many plant types.²⁰³

Eucalypts have evolved rich in flammable waxes and volatile oils. Some Australian species will only regenerate after fire destroys the host forest area.²⁰⁴

Although fire is integral to the Australian landscape, its cyclical frequency in the forests and shrublands of south-eastern Australia is about 14-40 years²⁰⁵ but can occur at intervals of less than 10 years.²⁰⁶

Plant species that provide fuel for fires vary widely across the state and ecosystems are highly diverse. As such, burning (either natural or managed) that is more frequent than historical cycles may effect ecosystem functioning and biodiversity in complex ways.²⁰⁷

Similarly, the role of climate change driving changes in fire ecology is impossible to predict with certainty.

While we may expect an increase in the potential for bushfire, as drought and fire weather become more common, the exact effect on intervals between bushfire events depends on a number other factors, such as fuel availability.

Rising temperatures, decreased water availability and increased atmospheric CO₂ may be working in opposite directions to influence fuel growth depending on local climate and dominant plant species. This means that changes in fuel availability will be specific to ecosystems and local climate and difficult to predict at a large scale.²⁰⁸

Fire and communities

Our planning efforts also grapple with the level of complexity which plays out in this environment.

The *Fire Danger Rating Scale* calculated to reflect a combination of factors - high temperatures, strong winds and dry fuel - is familiar and signals "Fire Weather".

Ratings are based on the Forest Fire Danger Index (FFDI) or Grassland Fire Danger Index (GFDI) which summarise weather conditions and fuel dryness. An artefact of the 1960s, the index was never intended to exceed a rating of 100. The Black Saturday conditions produced values of up to 200.²⁰⁹ On Black Saturday these weather conditions and high fuel load meant that fire spread rapidly and unpredictably after ignition, often exceeding the capacity for containment.²¹⁰

The response to our now elevated understanding of the risk of fire was to introduce a 'new' category of risk, *Code Red*, for potentially catastrophic fire-risk days (Figure 39).

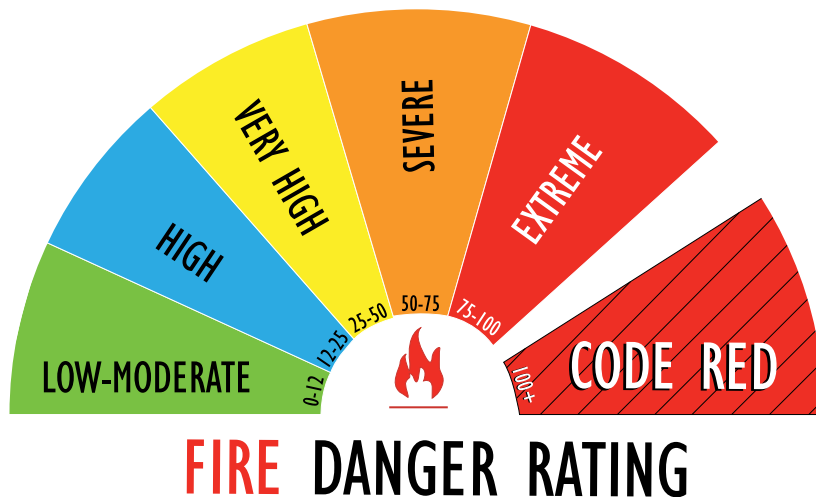


Figure 39:
Fire Danger Rating.
Source CFA.

On the new risk wheel, conditions rated as “extreme” and “code red” (ratings in excess of 100 FFDI or 150 GFDI) are hot, dry and windy. If a fire starts and takes hold on such a day, it is envisaged that it will be uncontrollable, unpredictable and fast moving.²¹¹

5.2 The complexity of impact

Losses felt in the aftermath of bushfires are often expressed in financial terms and, sometimes, in social impacts.

This unnecessarily narrows the potential impacts. The consequences of fires are wide-ranging, stretching well beyond the purely financial or human centred.

Environmental Impacts

Environmental impacts include immediate and short term reductions in air quality. Water quality, both potable and commercial, is also adversely impacted. Soil erosion can result from the denuding of the landscape, and whilst rainfall events might be welcome they will only exacerbate this problem by polluting catchments. Biodiversity losses are clear and often reported.²¹² It has also been suggested that the loss of wildlife corridors can adversely impact biodiversity, in particular vulnerable or threatened species.

Human Health Impacts – water quality in large and small townships

Bushfires have a high capacity to disrupt drinking water supplies across Victoria. The negative impacts on drinking water supplies usually manifest themselves in two ways. Firstly, the fire destroys treatment or distribution assets, which disrupts a water corporation’s ability to treat raw water to a drinking water standard, and/or distribute treated drinking water to customers. Secondly, the fire negatively impacts on the catchment areas from which the raw water is harvested. Fires in catchment areas usually lead to a deterioration in the quality of the raw water, which may result in the water being unable to be treated to a drinking water standard.

Rural and regional drinking water supplies in Victoria are managed by regional water corporations. They have the responsibility of ensuring that their customers have access to safe drinking water. In the event of a bushfire affecting drinking water quality, the affected water corporation will provide advice to its customers. This advice may consist of advice to either boil the drinking water prior to consumption, or not to use the water at all, or putting customers on restrictions to conserve the available supply of treated water, as happened at Kilmore after the Black Saturday bushfires. If the water is not safe to consume, even after boiling, the water corporation will organise an alternative supply of drinking water.

The impacts of large scale bushfires on drinking water supplies have been experienced for many years after the fires have been extinguished, as in some areas of the state, raw water quality has changed markedly, and semi-permanently, after fires. This has required water corporations to invest in new infrastructure, to help manage ongoing risks to drinking water quality.

Townships may find it necessary to introduce water restrictions following fires, due to soil erosion.²¹³ Erosion changes the chemical properties in soil, and releases increased levels of nutrients, metals and toxins into surrounding waterways causing reductions in water quality.²¹⁴ These effects may not be felt until long after the fire itself and can exacerbate other environmental stresses.

In 2006, bushfires at Mt Lubra in the Grampians destroyed large tracts of the catchment, but the critical impact on water resources was avoided until the major floods of January 2011 washed large amounts of ash and debris into Lake Bellfield - the principal source of town water for Horsham in the Wimmera. Water quality in the region is still adversely impacted in the Wimmera Mallee region.²¹⁵

Concerns about catchment degradation are real and widespread. The Thomson River catchment to Melbourne's east supplies 36% of Melbourne's reservoir water and serious impacts were narrowly avoided on Black Saturday.

Broader social impacts

Social impacts will be broad and profound. Immediate health impacts occur from direct exposure to fire and smoke.

Bushfire conditions also heighten stress. Mental health issues are regarded as a significant by-product of many of the physical manifestations of climate change events. Extreme events like floods have mental health consequences, as does the long attrition involved in protracted dry weather events like drought.

Over 2,000 homes were lost during Black Saturday with devastating consequences, not just to life and property.

In such circumstances people are driven to seek temporary accommodation beyond their communities. Social networks and the social cohesion which we know promotes better responses to climate change impacts are destroyed. People have to contend with social isolation and with feelings of loss and grief.²¹⁶

Family violence reportedly increases after natural disasters²¹⁷ and research is currently underway to determine the correlation between fires and relationship violence in Australia.²¹⁸

Quantifying losses – financial

Financial loss and costs of severe bushfires, again a partial narrative, will be significant after fires.

Scholarship out of the East Melbourne based Bushfire Cooperative Research Centre (CRC) and RMIT University has assessed in detail the economic impacts of five major bushfires, by assigning financial values to environmental and social impacts and combining these with directly measurable financial losses (Figure 40).²¹⁹

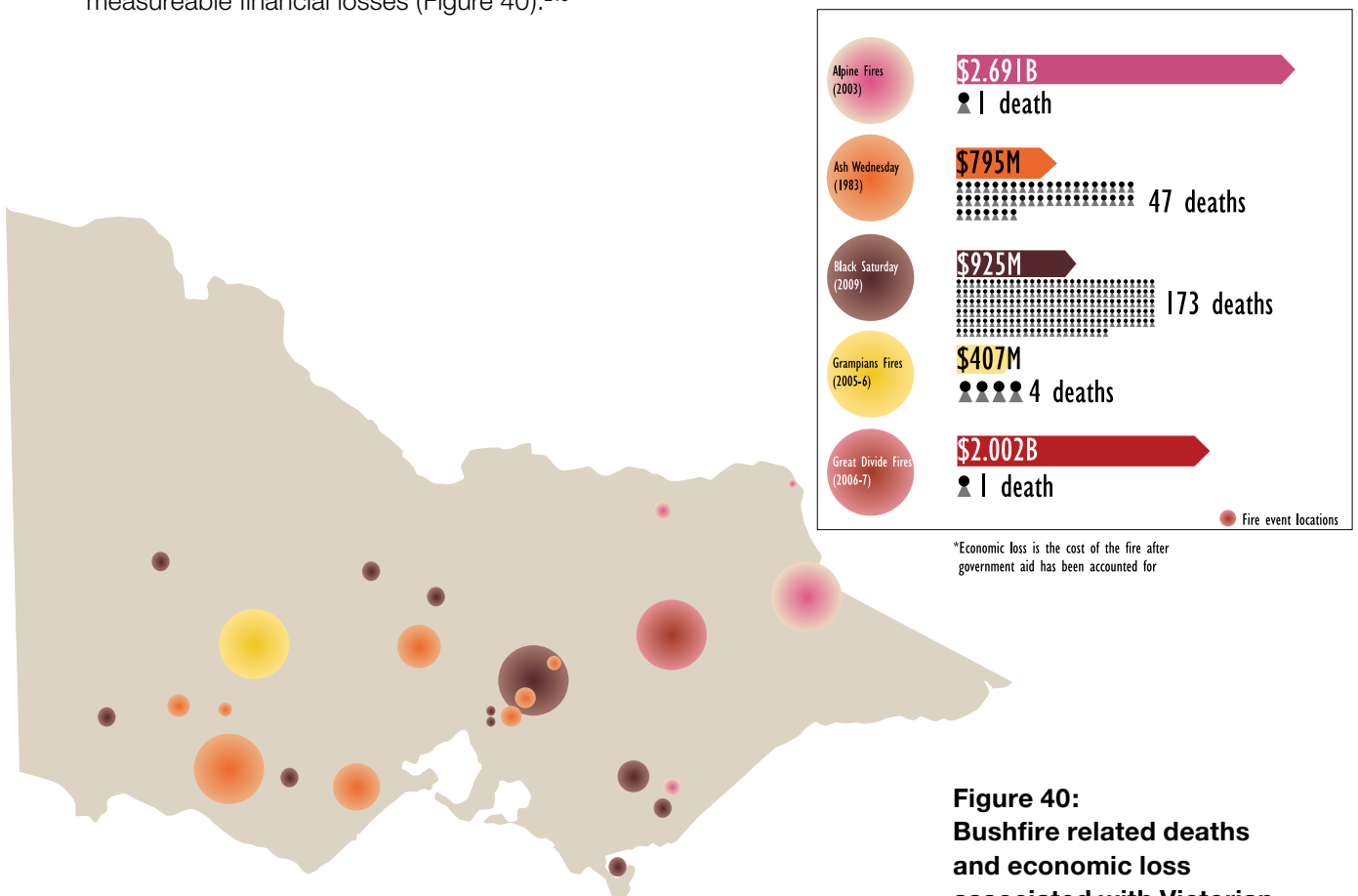


Figure 40:
Bushfire related deaths and economic loss associated with Victorian fires.²²⁰

Source Bushfires CRC, CfES developed infographic.

Primary production is the major loss and comes in the form of agricultural assets (including buildings and fencing), loss of crops, harvestable timber and livestock.

Other substantial financial losses include the impacts on small business and tourism. A \$200M downturn in tourist activity occurred in the northeast of Victoria and in Gippsland in the aftermath of the 2006-07 bushfires.²²¹

In addition to the losses expressed in monetary terms, we also need to be cognisant of the 'value' we as a community place on social losses such as disruptions to households and communities and the reduced health of individuals. Some of the greatest losses during these events were associated with the environment, such as impacts to biodiversity and the quality of our air and water.

Seasonal indices are useful in analysing past fires and determining fire links with climatic conditions.

5.3 Bushfires in a changing climate

As well as assessing day-to-day risk or severity of fire weather in the State, the Forest Fire Danger Index (FFDI) provides an indicator of seasonal severity. It does this by summing up the Forest Fire Danger Index for every day in the fire season.

Seasonal indices are useful in analysing past fires and determining fire links with climatic conditions.

To inform this process DSE has compiled a dataset that begins in 1901. The data records the severity of each fire season and plots it against long-term climatic data, such as temperature and rainfall anomalies.

We know that during the 20th century, Victoria experienced a number of decade-long wet and dry periods.

Dry periods and fire risk – fires are happening more often

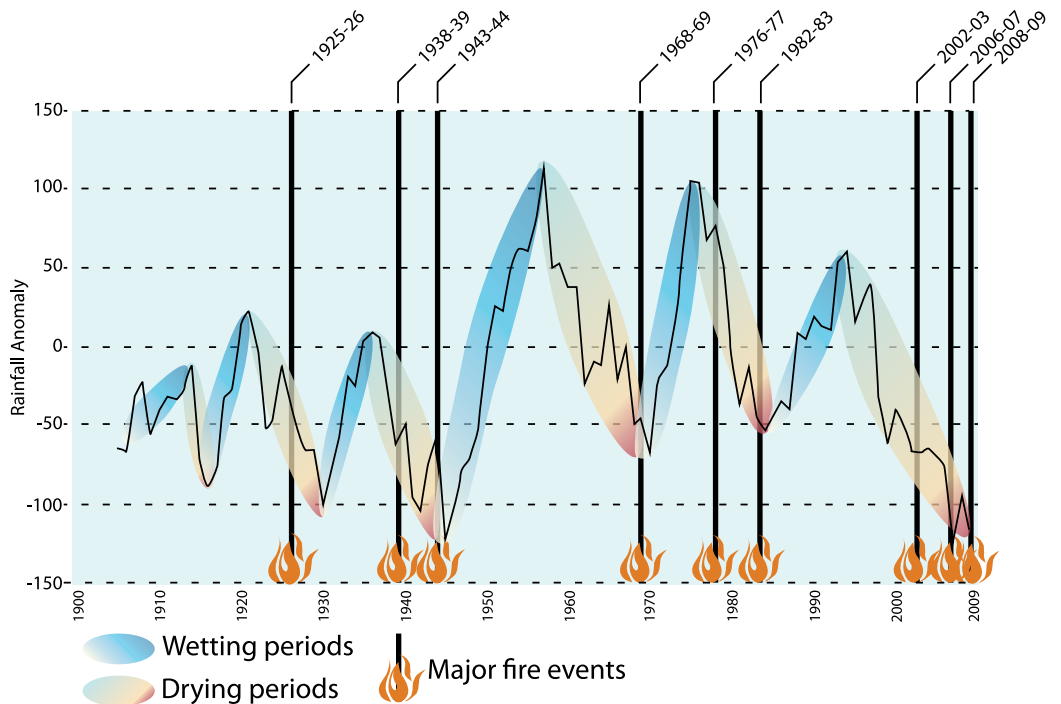
Dry periods result in large expanses of dry fuel and frequent fire weather.

The Millennium Drought lasted 13 years and is our most recent exposure to such conditions.

During these unprecedented dry conditions, Victorians experienced a string of severe fires, culminating in Black Saturday in 2009.

Figure 41:
The historic rainfall anomaly showing wet and dry periods between 1901 and 2009 with major fire events.

Source Department of Sustainability and Environment.



Severe fire seasons occur when rainfall decreases after heightened rainfall events have provided conditions in which fuel accumulates. So, the rainfall first provides the conditions in which a fire will later occur (Figure 41).

The data suggests fires are getting worse

The indices can also be used to analyse how the frequency of fires of different severity has changed over time and how the level of frequency might change in the future.

To determine this, each of the fire seasons on record was classified according to its impacts using the graduated scale: non-significant, important, serious, major and catastrophic.

Historically, the severity of fires has followed a predictable pattern.

Non-significant fire seasons were frequent - on average every second year since 1900.

Major and catastrophic fires have been rare, occurring in about 14 out of 100 years.

If we assume that the last 15 years of climate are more representative of future climate than the entire 20th century record, we see that the severity of fires in Victoria has changed in the period 1995-2009, when these events are compared to our complete record (Figure 42).²²²

When the indices data are analysed in more recent periods, it becomes clear that non-significant seasons are becoming rarer. Almost every season can be categorised as having produced fire events which can be described at least as “important”.

More concerning, the analysis of the data prompts the conclusion that “serious” and “major” fire seasons are becoming much more common.

This analysis of the data suggests that even though the number of fires may not have changed, their impacts are presently (and, upon extrapolation, in the future) expected to worsen.

It is anticipated that an increase in ‘serious’ - ‘major’ seasons may be more likely. Further - and of concern to planners, environmentalists, land managers, health professionals, governments and the general public - seasons with no significant impact may become a thing of the past.

More concerning, the analysis of the data prompts the conclusion that “serious” and “major” fire seasons are becoming much more common.

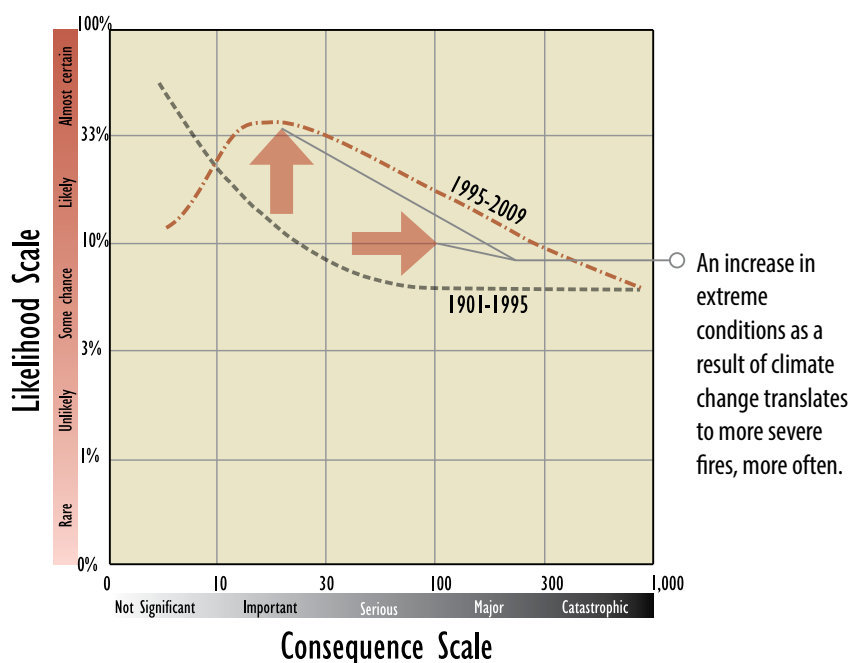


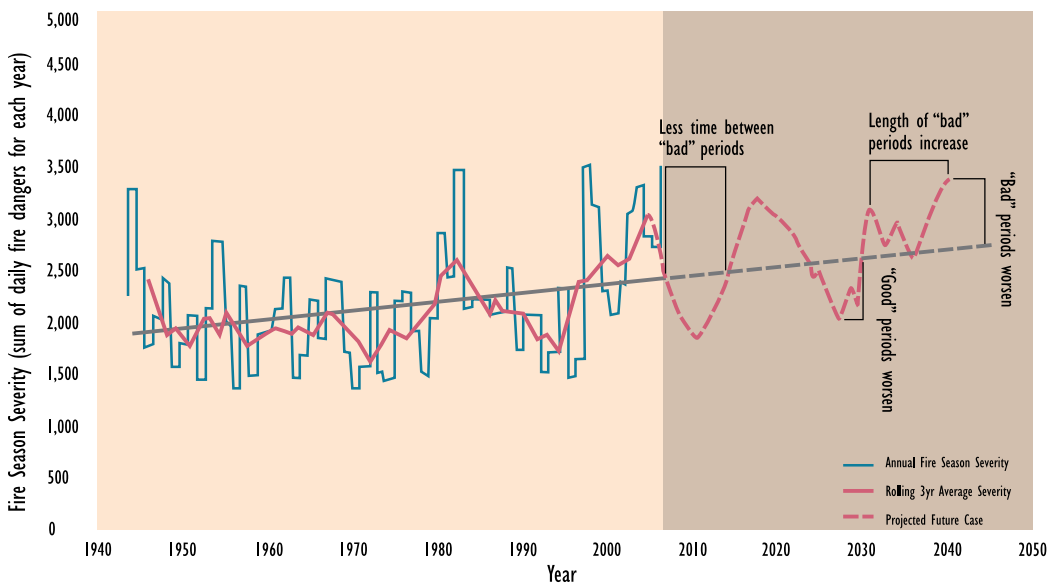
Figure 42:
Analysis of the occurrence and severity of bushfires in Victoria during the periods 1901-2009 and 1995-2009.
When compared to the 20th century, recent years have seen an increase in occurrence of loss-causing fires.
 Source Department of Sustainability and Environment.

Climate change and the danger of fire

It is self-evident that the severity of fire seasons is closely linked with low rainfall and soil dryness. Climate change, in our country, is suggested as a key driver of these conditions.

CSIRO projects from its own and other data that drier conditions will become more common in Australia in the coming years.²²³ Associated with these conditions, it would appear that fires are more likely to be ignited by lightning strike connected to increasing storm activity.²²⁴ The implication of these climatic projections, based as they are upon scientific analysis, is that the discernible trend of increasingly severe fire seasons is likely to continue (Figure 43).

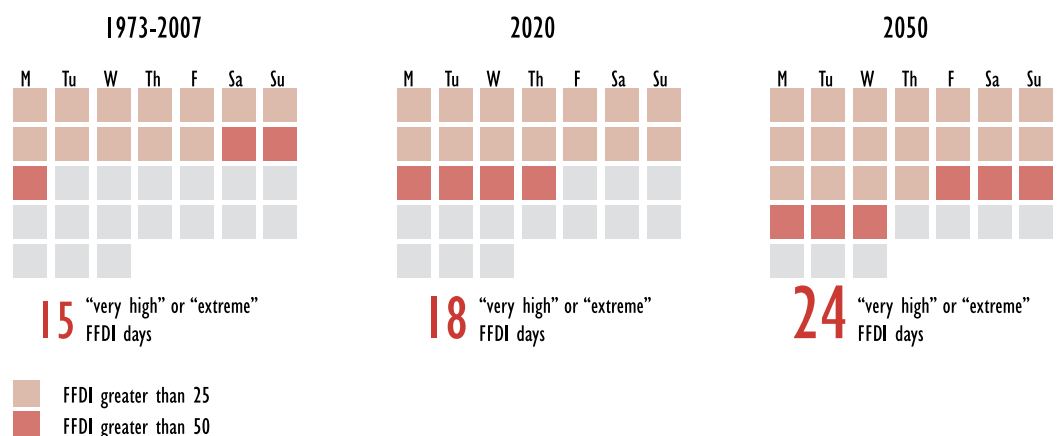
Figure 43:
The trend in fire severity in Victoria shows an increase.
Source Department of Sustainability and Environment.



Expressing this shift in fire danger by reference to the index rating tool, the number of days with Forest Fire Danger Index ratings of greater than 25 may increase across a range of 4-25% by 2020. By 2050 the range of increased risk may be 15-70% (Figure 44).²²⁵

The relationship between climate and bushfires fire is complex. This means that relatively small changes in temperature and rainfall have the potential to lead to large effects on the occurrence, intensity and impacts of fire. Such uncertainties call for robust planning approaches which recognise the implications of inaction.

Figure 44:
Projected increase in fire weather conditions in 2030 and 2050.²²⁶
Source Bushfire CRC, CfES developed infographic.



5.4 Bushfire risks in Victoria

Can we reduce fire impacts?

The VBRC recommended that the planning and building systems more explicitly respond to bushfire considerations. Central to this is ensuring that the necessary regulatory responses are triggered by an accurate assessment of the bushfire hazard according to criteria based on the best available science. Such mapping is the important foundation for ensuring that the existence of a bushfire hazard is explicitly recognised and that the appropriate risk assessments, through either a planning or building system response, is undertaken.

The approach above is now being taken forward, with updated mapping being prepared and extensive regulatory reform in both the planning and building systems being implemented in 2011. Such reforms reinforce the way in which planning and building can reduce the impacts of bushfire on human life, property and community infrastructure.²²⁷

Controlled burning

‘Controlled burning’ is often recommended as the most appropriate method of reducing the number of extreme fires.²²⁸

Successive state governments have committed to burning 5% of public land annually, as was recommended by the VBRC. Regardless of the political persuasion of the administration driving the target this plan has drawn criticism as arbitrary and inappropriate to the needs of many local communities and ecological systems. The final report of Bushfires Royal Commission Implementation Monitor recommended that this target – based solely on hectares burnt – be reviewed. The report commented that “a true test of the effectiveness of the planned burning program is the extent to which the severity of bushfire is reduced in high risk areas and bushfires are more manageable in these areas” and advocated that risk reduction, rather than area, be used to define controlled burning targets.²²⁹

Given the likelihood of increasing occurrence of fires in the future, identifying risks from extreme fires, both to communities and ecosystems, and reducing exposure where possible, is crucial.

Reduction of exposure

Reductions in exposure lessen impacts and this need is being met by land buy-backs and the prevention of building on at-risk sites.²³⁰

Evidence indicates that 92% of house loss occurs within 150 metres of the bushfire hazard. Beyond this area house loss can also occur from long distance embers²³¹ affected by extreme weather and fire behaviour. In Victoria there are new rules about clearing and maintaining defensible space around buildings.²³²

Evidence indicates that 92% of house loss occurs within 150 metres of the bushfire hazard.

Unsurprisingly, severity of fires has been observed to be strongly correlated with greatest losses²³³ including biodiversity losses (e.g. the Grampians, and Great Dividing Range fires).²³⁴ Bushfire management, including controlled burning, can reduce fire severity, reducing the exposure of communities and ecosystems to code-red fires and their attendant impacts. However, this needs to be sensitive to local ecological requirements and their natural burning regimes, which will often be much longer (decades rather than years) than the timed target burns currently being imposed.

Responses seeking to minimise fire ignition and intensity through active land management, for the protection of biodiversity will be discussed in greater detail in the *Victorian State of Environment Report (2013)*.

Identifying risks

Identifying fire risks is essential for planning for the future.

Victoria is quickly moving to a more consistent and streamlined identification of the bushfire hazard for the purpose of regulatory planning and building responses. In line with recommendations from the VBRC, updated criteria based on the best available science and applied consistently by skilled technicians forms the basis for updated mapping in the planning system (Bushfire Management Overlay) and the building system (Bushfire Prone Area).

Unlike many other hazard-based mapping products, mapping in the planning and building systems are readily available on publically accessed websites and provide State-wide information. This is owing to the effect they have on property rights and people's entitlements to develop their land. This also means that planning and building systems are often taken as proxies for other systems and processes, particularly those that seek to identify risk rather than hazard.

Mapping the bushfire hazard according to consistent criteria that responds to the purpose of the map (in this case, triggered regulatory response in the planning and building systems) provides a firm basis for regulatory systems to consider risk as part of the development approval process (either a building permit or a planning permit).²³⁵

The approach in Victoria provides for three tiers of bushfire hazard identification:-

- Low – No building or planning response.
- Medium – Building system response only.
- High – Planning system and building system response together.

This tiered approach ensures that the regulatory tools available are tailored to the hazard.

Consistent with the recommendations of the VBRC, updated mapping has been accompanied by regulatory reform to the Victoria Planning Provisions, planning schemes and the building regulations. These make much more explicit the policy response to the different levels of bushfire hazard identified in the mapping, the risk assessments which must be undertaken, and the impacts this has on securing more fire-resilient development.

The State Planning Policy for bushfire (Clause 13.05 of planning schemes across Victoria) explicitly requires that the bushfire hazard be identified on the basis of the best available science. As this science improves, including in relation to the impacts of climate change, the regulatory systems will need to be responsive.

The VBRC delivered the basis for improving the capacity to protect life and property and respond to future fire events. The next challenge is building on these far reaching reforms to incorporate amplified risks due to climate change factors.

Responding to the VBRC, the Victorian Government has released maps of newly classified Bushfire-Prone Areas (BPAs). As these are defined by the presence of flammable vegetation, they cover approximately 80% of the state. The BPA scheme is a tool for applying fire regulations and is not intended to inform the public about present day or future projected, climate propelled fire risks.

The public can access a web interface which maps the proximity of homes to bushfire prone areas and refuge areas. This mapping of bushfire-prone areas is a valuable tool in making planning decisions.

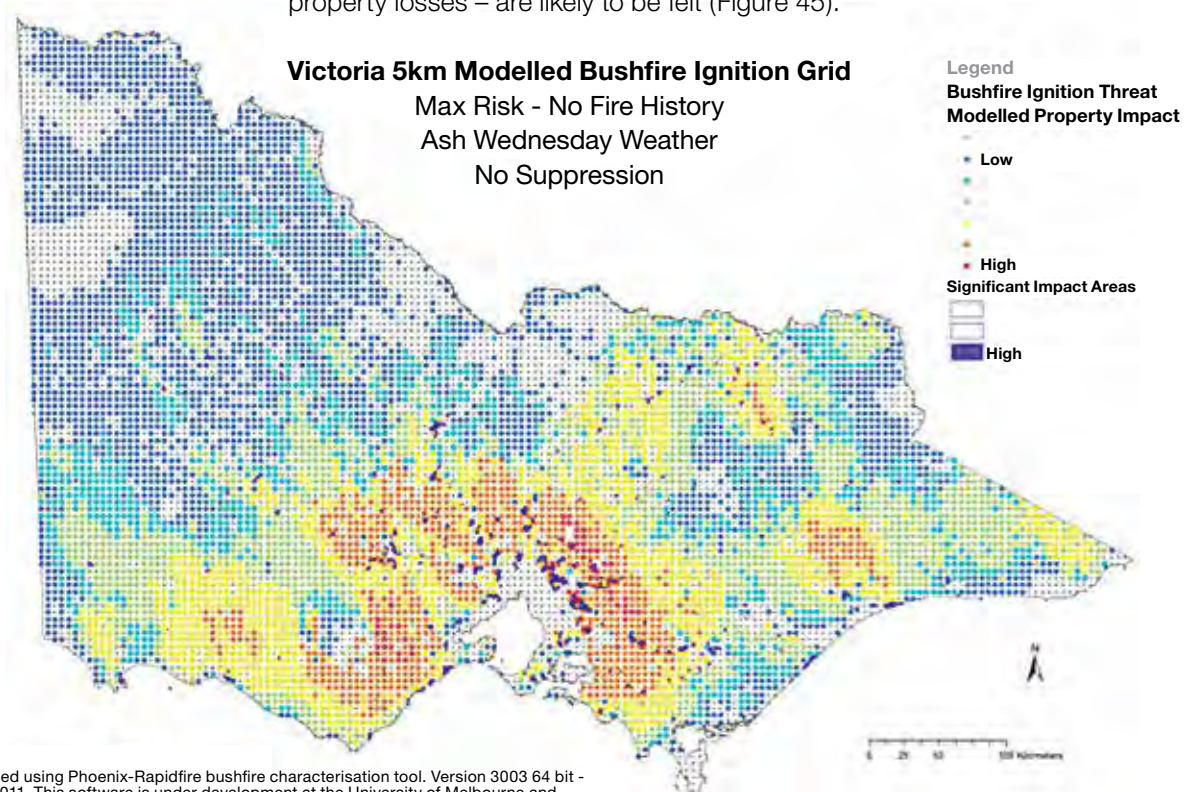
Landowners or developers seeking to construct new homes in designated bushfire-prone areas now need to meet new regulations in order to build.²³⁶

The public can access a web interface which maps the proximity of homes to bushfire prone areas and refuge areas. This mapping of bushfire-prone areas is a valuable tool in making planning decisions.

Comprehensive risk mapping in Victoria

DSE has used the bushfire characterisation model Phoenix-Rapidfire to model the location of areas at greatest risk from code-red level bushfires, assuming that there is no fire management regime in place.

This reveals where the most significant impacts – defined here as property losses – are likely to be felt (Figure 45).



Produced using Phoenix-Rapidfire bushfire characterisation tool. Version 3003 64 bit - 7 Apr 2011. This software is under development at the University of Melbourne and Bushfire CRC. It is being trialled by DSE Land and Fire Management. This map is only suitable for broad level planning use and should not be used for local level planning.

Figure 45:
Map of broad, relative bushfire threat or risk landscapes across Victoria.

Source Department of Sustainability and Environment.

This work is invaluable for public awareness and education to ensure understanding of the risk to life and property from bushfire. It would compliment more detailed specific purpose mapping including those used in regulatory systems.

The benefits to Victoria of DSE research into fire regimes have been demonstrated in a pilot project focusing on the Otway region.²³⁷ This pilot has evaluated how fire management options affect outcomes for community protection, biodiversity and water. Although further research is still needed to validate model outcomes, this is providing crucial insights into setting priorities when weighing up competing demands and managing for several objectives. Such insights will be vital when engaging with communities to set priorities for risk reduction.

Initiatives of this nature are also vital in moving beyond the purely responsive management of fire impacts towards rigorous testing of management strategies under a range of conditions and building capacity to engage in adaptive management. Although climate change scenarios are not explicitly included, it is possible to incorporate these events into decision making processes to progressively incorporate greater resilience into our fire planning and response capacity as our knowledge of changes in climatic features develops.

National Data Grid

Although it is relatively simple to quantify potential fire losses in terms of burnt properties, less tangible impacts are harder to include and local community values are absent from the current mapping of Victorian bushfire-prone areas.

An approach that will allow greater integration of these values into risk assessments is the planned inclusion of fire-risk planning into the proposed National Data Grid (NDG). The NDG, hosted in Carlton by the Cooperative Research Centre for Spatial information (CRC SI) seeks to provide an Australia-wide platform to integrate data from numerous providers across the country and create a portal through which users can combine and interrogate data.

Further, and in our own region, as part of its fire management planning, the Emergency Services Commission, Victoria, has created a Consequence of Loss database that maps economic, infrastructure and environmental assets that are prone to fire damage.

Using this database, areas containing high-value natural and built assets can be identified using consistent criteria.

These data were originally intended to be made available for use by local planners to identify assets that are of high value in local emergency planning (for example, timber bridges that act as a sole transport link for a community). However, before this system could be implemented the Black Saturday fires occurred and the project was not completed as planned.

The Emergency Services Commission now intends to integrate this database into the proposed National Grid to create consistent data inputs to mapping areas of high value (and therefore high risk) from natural disasters.

Instructive international and other national examples of fire risk communication

Approaches that include educating those at risk to better understand their risk exposure, communicating the messages with more clarity and more forcefully and measuring community values are being pursued in several jurisdictions around the world.

USA

In the southern USA, the Southern Wildfire Risk Assessment (SWRA) project is being used to communicate bushfire risks for 13 states.

This initiative identifies those areas most prone to fires and provides several risk output metrics. These metrics are focused on identifying those areas where mitigation measures will be of greatest value and should be prioritized.

Moreover, the outputs from SWRA are used as a tool to facilitate communication with residents to educate and address community needs and priorities. Many southern states use the SWRA results for local government agency partnerships for both mitigation planning, prevention and outreach.

Although it is relatively simple to quantify potential fire losses in terms of burnt properties, less tangible impacts are harder to include and local community values are absent from the current mapping of Victorian bushfire-prone areas.

This portal offers a much higher resolution of fire risk than a straightforward presentation of the presence of flammable vegetation.

In Texas, the initial SWRA has been updated and deployed using a web mapping application called the Texas Wildfire Risk Assessment Portal, or TxWRAP (tex-rap). TxWRAP provides several custom geo-web and geo-mobile applications that provide easy access to the risk information for mitigation and prevention planning. The applications have been built for non-GIS users (including the public) and providing analysis capabilities for analysing risk data for specific project areas. The suite of applications are focused on state and local government fire agencies usage, and are a primary mechanism for the Texas Forest Service to create awareness, educate the public, and empower ranchers and agencies with proactive fire planning.

This tool enables the assessments generated by the State of Texas to be presented to members of the public and local agencies via a web portal that allows users to view risk levels at high resolution.

The primary drivers for this work were demands for a formal regulatory process using risk assessment as the primary mechanism for mitigation and to provide a relatively simple mechanism for local planners and fire managers to access and assess this information.

Figure 47 is an example output from this portal. The Public Viewer application provides a tool that helps local homeowners determine their risk, providing general mitigation guidelines, and connecting them to a local planner where they can get more detailed information. This is referred to as the *What's Your Risk?* tool.

This portal offers a much higher resolution of fire risk than a straightforward presentation of the presence of flammable vegetation.

This level of detail aids more rigorous planning by both communities and resource managers.

TxWRAP was released in April 2012. In the first three months the site has had high usage and traffic and has helped the Texas Forest Service forge partnerships with many other Texas agencies, fire departments and private landowners in establishing mitigation and prevention programs that were not possible before. Enhancements to the site are underway to provide more applications focused on specific planning priorities and business requirements.



Figure 46:
Screenshot of the
TxWRAP portal.²³⁸

This model contains an explicit consideration of values that will be affected by fires to assess risks.

So, high-risk areas are defined not only by the likelihood of severe fires but also reference a grading of loss exposure.

Potential fire impacts are assessed in terms of damage to agriculture and infrastructure and penetration of fire into urban areas.

Similar projects have been carried out in many fire-prone jurisdictions in the USA where agencies have worked with consulting firms to identify high-risk zones that incorporate community values which extend beyond straightforward property and financial losses. GIS analysis and web portals are routinely used to improve public access to the information.²³⁹

Parks Tasmania

Closer to home, Parks TAS have developed a similar risk assessment model that integrates fire likelihood with metrics of consequence.²⁴⁰

This expands on SWRA because, alongside agricultural and infrastructure losses, it includes the impact of fire on ecosystem components (flora, fauna and water) and cultural heritage, enabling the community to define consequences of fire that are aligned with their own values and develop risk mitigation measures accordingly.

Planning and education

Victoria is home to world class expertise in identifying and assessing bushfire risks in a changing climate. As this capacity to identify high-risk, and climate change exposed areas increases, options for retreat and adaptive planning will need to be clearly explored and explained to the public.

Controlled burning, when guided by appropriate risk management is an important tool to reduce fuel loads and the intensity of naturally occurring bushfires but should not be used in isolation. An integrated approach to reducing risks from fire also includes government intervention to reduce exposure in the highest risk areas (for example, planning regulations or the current relocation policy) and public education.

In at risk areas there needs to be greater engagement with communities across the whole spectrum of issues – from readily understood and immediate fire risk to climate change exposure and eventualities.

At present, Victoria uses the *Prepare, Act, Survive* approach in which householders must decide to either invest in the resources to defend their property during a fire or leave well before a fire starts. As part of this, the CFA advise that homes will not be defensible during a Code Red fire.

As peri-urban areas expand, and some people choose a rural lifestyle setting, the exposure to bushfire risk can be increased. New residents can be unfamiliar with the environmental context and hazards associated with non-urban locations. These populations can become increasingly vulnerable to fires.²⁴¹

As well as reducing exposure wherever possible, through regulation and planning and building controls, we need to deliver coordinated education and training for those choosing to live in high-risk peri-urban and bush areas.

A policy of this nature is only appropriate when communities are capable of identifying fire conditions, and anticipating likely conditions for a Code Red fire - when they are empowered to act autonomously and respond appropriately to minimise loss of life during fires. With education and training, an approach of devolved responsibility will be appropriate for the majority of fire events.

CSIRO reports that weather associated with high fire danger has shown a rapid increase in the late 1990s to early 2000s at many locations in south-eastern Australia.²⁴² Climate projections for a hotter and drier state, mean we should continue our efforts for fire preparedness, including support for community responses and state-wide processes to assist and protect people.

CHAPTER SIX - HEATWAVES

More Australians die from heatwaves than from any other form of natural disaster²⁴³ and heat events have killed more people than any other natural hazard experienced in Australia over the past 200 years. And, heatwaves do not pass with the setting of the sun, rather we are seeing increasing instances of hotter nights.

Hot drying periods are expected to become more frequent and more intense due to climate change.

6.1 The heatwave experience

The January 2009 Victorian heatwaves (temperatures were 12-15 degrees above normal)^{ix} hastened the deaths of 374 people. South Australia experienced contemporaneous heat events. Perth has experienced^x eight heat events in the period November 2011 to March 2012. The CSIRO *State of the Climate 2012 report* says that heatwaves will be a problem of increasing frequency and intensity across the continent (Figure 48). There is a clear public policy need to formulate an adaptation plan for heat related impacts.

Beyond our own heatwave data, heatwaves internationally have contributed to large scale deaths, such as the 2003 European heatwave in which around 52,000 Europeans died, including more than 14,800 deaths in France alone.²⁴⁴

However, it is not only humans who are impacted, it is also the natural estate.

In the agricultural sector production, livestock and crop losses have long been a product of heatwaves²⁴⁵ and management interventions and long-term planning is necessary.

The key public policy issue for heatwaves is to ensure our community, particularly our vulnerable members and our health systems and our urban centres, agriculture sectors and infrastructure are more resilient and/or more adaptive to heatwave conditions.

Future heatwave events

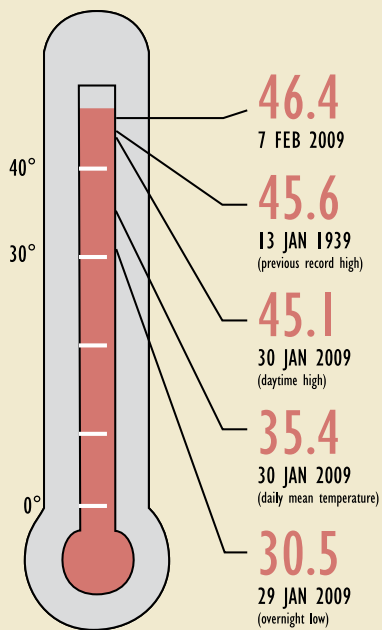
Hot drying periods are expected to become more frequent and more intense due to climate change. Increased monthly mean temperatures and also increased extremes of high temperature are expected to occur producing more frequent and more intense heatwaves.²⁴⁶

For IPCC/CSIRO scenarios where there are continuing high-emission levels of greenhouse gases, the incidence of days over 35°C is predicted to increase by around three times for Melbourne by the end of the 21st century.²⁴⁷

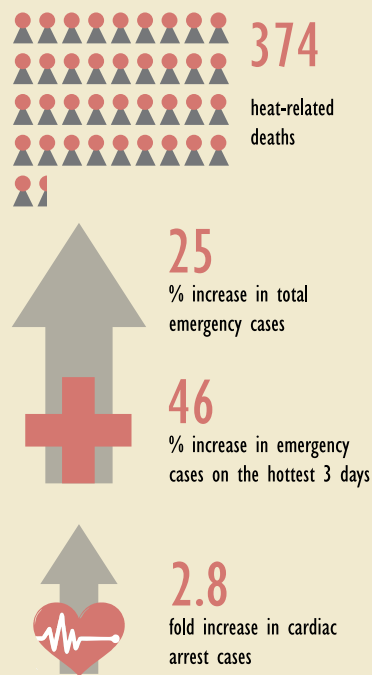
ix Victoria's highest temperature on record is 48.8°C on 7 February 2009.
x Prolonged periods of high temperature durations.

On **30 January 2009**, Melbourne's daily mean temperature* exceeded **35°** for the first time in history

Notable temperatures: 2009 heat wave:



Notable health statistics: 2009 heat wave:



*daily mean temperature is the average hourly temperature readings throughout the day

Days over 35°C per year in Victoria (existing and projected)

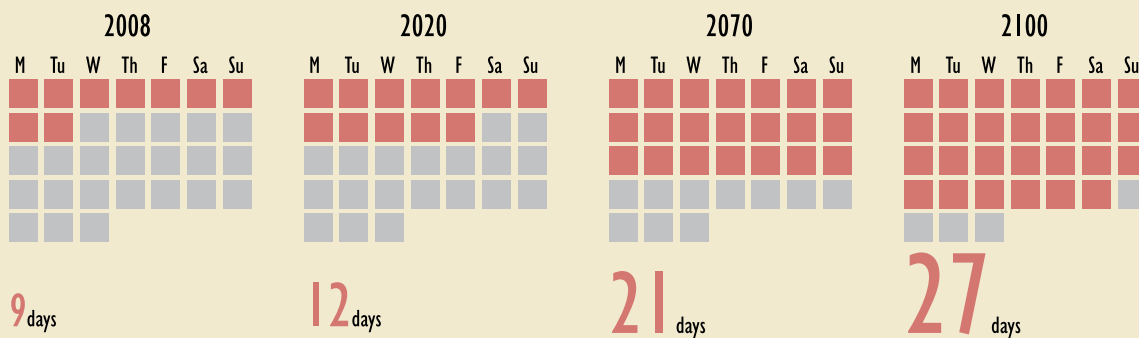


Figure 47:
Source Department of Health, CSIRO. CfES developed infographic.

This change in the climate will impact different places in different ways – as the study of heatwaves suggests is the case.

In city settings we will see the number of hot days compounded by the urban heat island effect.

6.2 Impact of heatwaves

Our cities in heatwaves

Heatwaves, including the phenomenon of increasing hot nights, in respect of which the elderly are particularly vulnerable, are intensified by the urban heat island phenomenon.

The urban heat island is created through the absorption of heat by materials such as concrete and asphalt, which in high density areas, such as metropolitan Melbourne, result in temperature increase.²⁴⁸ Heat generated by energy usage also contributes to the urban heat island effect.

This phenomenon was first described in the early 1800's by Luke Howard a pharmacist/chemist who wrote in *The Climate of London*:

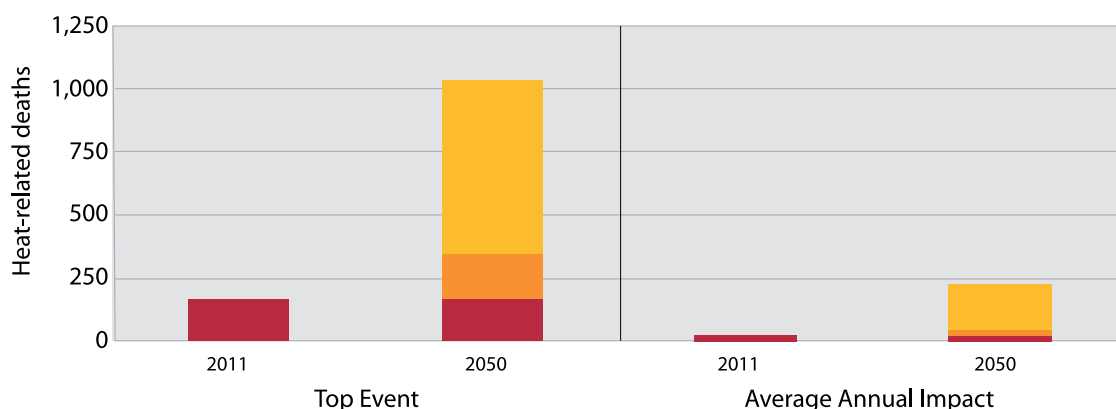
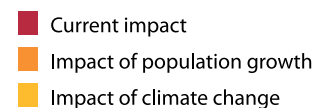
But the temperature of the city is not to be considered as that of the climate. It partakes too much of an artificial warmth, induced by its structure, by a crowded population and consumption of great quantities of fuel.²⁴⁹

People in Heatwaves

Recent modelling of a 'business as usual' climate change scenario for Melbourne suggests that by the middle of the twenty-first century, there could be a death toll two to three times higher in the most extreme heat events than we have experienced to this point (Figure 48).²⁵⁰

This modelling projects that climate change will be the main contributing factor to heat-related deaths by 2050.²⁵¹

By 2050 heat-related deaths could be 2 to 3 times higher in Melbourne, with about 80% of this increase being attributed to climate change*



*represents a 'middle of the road' climate change scenario, as modelled in "Protecting human health and safety during severe and extreme heat events," PWC, 2011.

Figure 48:
Price Waterhouse Coopers,
Protecting Human Health
and Safety during severe and
extreme heat events 2011.²⁵²

The impact of heat on human health is not well understood. To survive the human core-body temperature needs to remain around 37°C. If the body produces or absorbs more heat than it can remove through sweating the core-body temperature will increase (Figure 49).

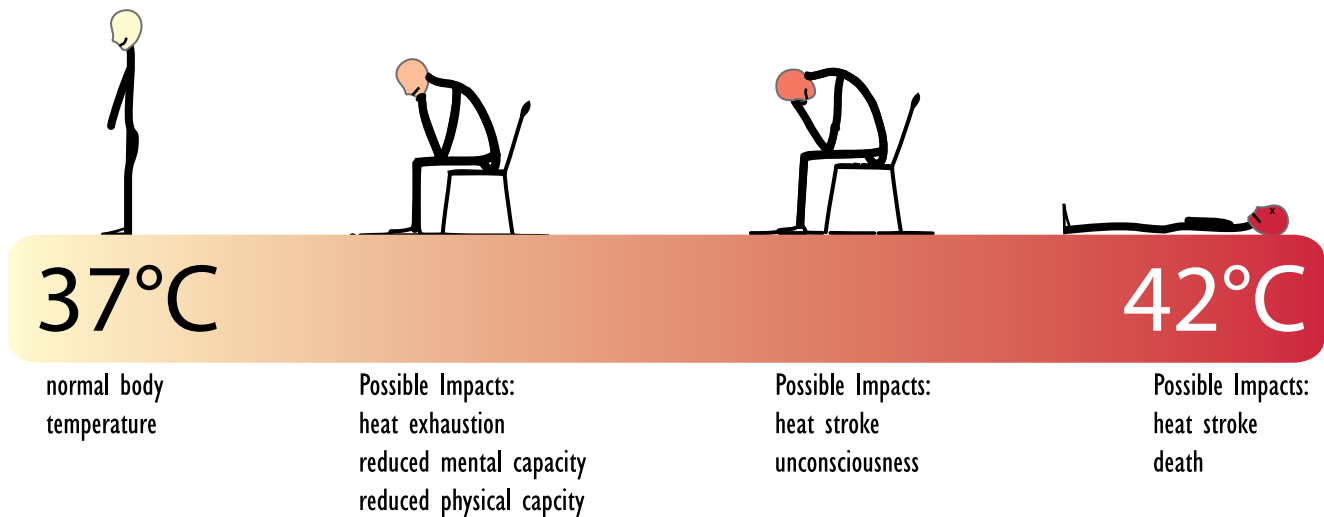


Figure 49:
Source Climate Commission, 2011.²⁵³

The most common causes of death seen during heatwaves are related to cardiac conditions, asthma and other respiratory illness, kidney disease, diabetes, nervous system diseases and cancer. For those people already in vulnerable circumstances – for instance those with health problems (such as people on medication or with pre-existing illness and/ or injury), older people and low socioeconomic groups – the heat only exacerbates their vulnerability.

The capacity to respond to the physical and psychological effects of heatwaves is compounded by the fact that health services are heavily impacted during heatwaves and much of the impact of heatwaves is felt at night as heat does not abate. Services including ambulance call outs, emergency department presentations, and nurse on call services receive additional requests during heatwaves to deal with heat-stress patients.

Heat related psychological affects on people

Less commonly known, is that heatwaves have been associated with psychological health impacts. Mental illness is becoming more common in Australia. In any given year, one in five Australians suffers from a mental disorder of some kind, potentially making millions of people more vulnerable to mental ill-health in an increasingly hostile climate.²⁵⁴

The emotional and psychological toll of extreme weather events and natural disasters can linger for months and sometimes years, affecting extended families, people's capacity to work and community wellbeing. Higher rates of drug and alcohol misuse, violence, family dissolution, and suicide have been marked as 'more likely' to follow more extreme weather events. Evidence is beginning to emerge that drought and heat waves lead to higher rates of self-harm and suicide - as much as 8% higher.²⁵⁵ An increase in violence and anti-social behaviour is also a potential implication of heatwaves, particularly when alcohol is involved.²⁵⁶ Recent studies also indicate a correlation between very hot and humid conditions and hospital admissions for facial fractures. Victoria Police have commented that they need to consider the operational implications of hotter conditions.²⁵⁷

People most vulnerable to heatwaves

Heatwaves can affect anybody, including the young and healthy. However, there are certain groups that are more vulnerable to its effects due to factors such as their age group, health, environment, social and economic circumstances, location or occupation.

During the 2009 Victorian heatwave most of the increase in mortality occurred in people aged 75 or older.²⁵⁸ An analysis of heat-related emergency department data identified and assessed heat vulnerability in Victoria, showed people aged 65 years or more were significantly more likely to present to an emergency department in Melbourne with a heat-related condition than people from other age groups. Adding to this, people who have a medical condition and people taking medicines that affect the way the body reacts to heat are vulnerable to extreme heat events.

Lower socio-economic groups are particularly vulnerable to heat as they have a higher prevalence of heat related health risk factors and tend to live in some of the most heat exposed parts of the city. They also have fewer financial resources to invest in climate adaptation actions, such as the installation of air conditioning, and are more likely to live in rental properties with limited capacity to undertake building improvements. Heatwaves are also known to affect mood and psychological well being, impair concentration and make people feel lethargic. This only adds to the heat related health risk for lower socio-economic groups, further compounding the already well established link between social disadvantage, deprivation and poor health outcomes.

During the 2009 Victorian heatwave most of the increase in mortality occurred in people aged 75 or older.²⁵⁸

Land Surface Temperature

Low Income Households

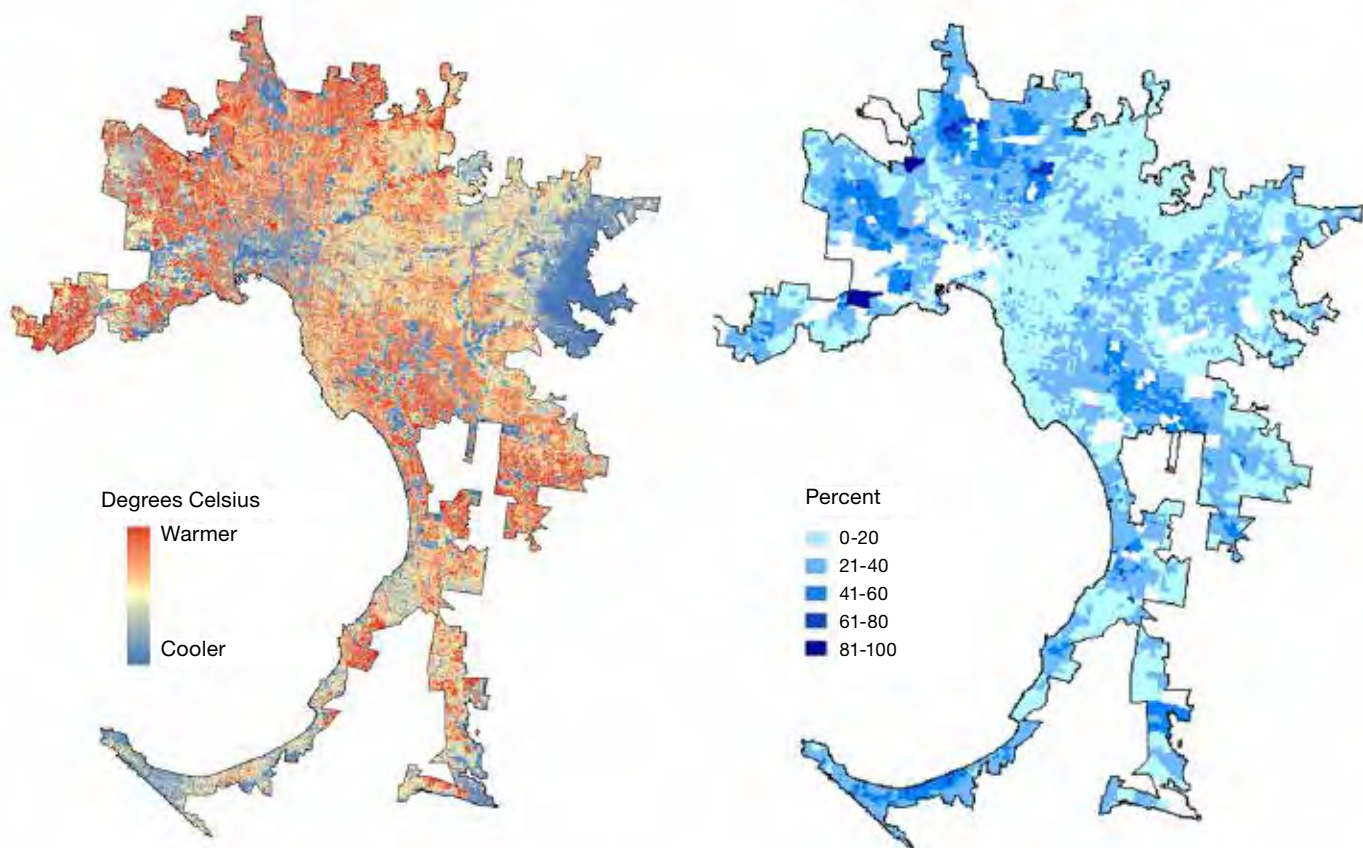


Figure 50: Map showing land surface temperatures (LST) of metropolitan Melbourne was derived from Landsat TM data collected on 10 December 2006. Image obtained from Geoscience Australia and processed/analysed by CSIRO. Map showing percentage of low income households is based on ABS Census 2006 data and census collector districts, with low income defined as equivalised household income between \$1-399/week.

Source Beaty, Matt; Barnett, Guy; Meyers, Jacqui; Spinks, Anneliese (2012). Heat vulnerability of low income households in four Australian cities. 2012 NCCARF National Adaptation Conference: Climate Adaptation in Action: Sharing Knowledge, Melbourne, 26 - 28 June 2012 . NCCARF. 1p.

Impact of heatwaves on our natural assets

Severe heatwaves can have serious impacts on the health of native species, particularly when heatwaves coincide with long periods of drought. The Victorian heatwaves in January and February 2009 resulted in the emaciation and deaths of several species including Grey-headed Flying-foxes and possums, particularly Ringtail Possums.²⁶⁰ Other animals known to suffer from heatwaves include koalas and bird species. Juveniles are often at most risk from extreme heat periods.

Native flora is also threatened by heatwaves. Seedlings, in particular, are at risk from the combination of heatwaves and drought.²⁶¹ In addition, the increased occurrence of extreme events is likely to lead to shifts in the composition of vegetation and the loss of habitat.

Biodiversity loss

Whilst many Australian species are adapted to cope with occasional heatwave events, the projected increase in the severity and frequency of heatwaves is likely to have significant consequences for Victoria's native flora and fauna, with greater heat-related mortality rates expected in the future. Heatwave events resulting in high mortalities are of particular concern for threatened species already subject to a range of pressures. For example, the 2010 Western Australia heatwaves resulted in significant deaths of the Carnaby's Cockatoo.²⁶² The population of this endangered cockatoo has declined dramatically in recent years and such losses further increase the risk of extinction.²⁶³

Impacts of Victoria's 2009 heatwaves on Grey-headed Flying-fox²⁶⁴

Flying-foxes are sensitive to extreme temperatures because they tend to roost on exposed branches of canopy trees. During January and February 2009, two heatwaves resulted in the deaths of 4,868 flying-foxes from the Yarra Bend colony. This included 3,539 flying-fox deaths on 7 February when temperatures reached 46.4°C.

The mass mortality of Grey-headed Flying-fox during extreme heat events has been recorded elsewhere in eastern Australia. At least 19 other heat-related mortality events have been reported since 1994, resulting in over 24,000 Grey-headed Flying-fox deaths. This includes the death of 4,800 Grey-headed Flying-foxes after an extreme heat event in Sydney, in early January 2006. Before 1994, there were only three reported mass die-offs in eastern Australia, suggesting that these events have become more common and could be attributed to an increased occurrence of heatwaves.

Heatwave effects - agriculture

Victorian agricultural industries face a greater challenge of adapting to heatwaves than in many other parts of Australia.²⁶⁵

Figure 51:
CfES developed infographic.²⁶⁶

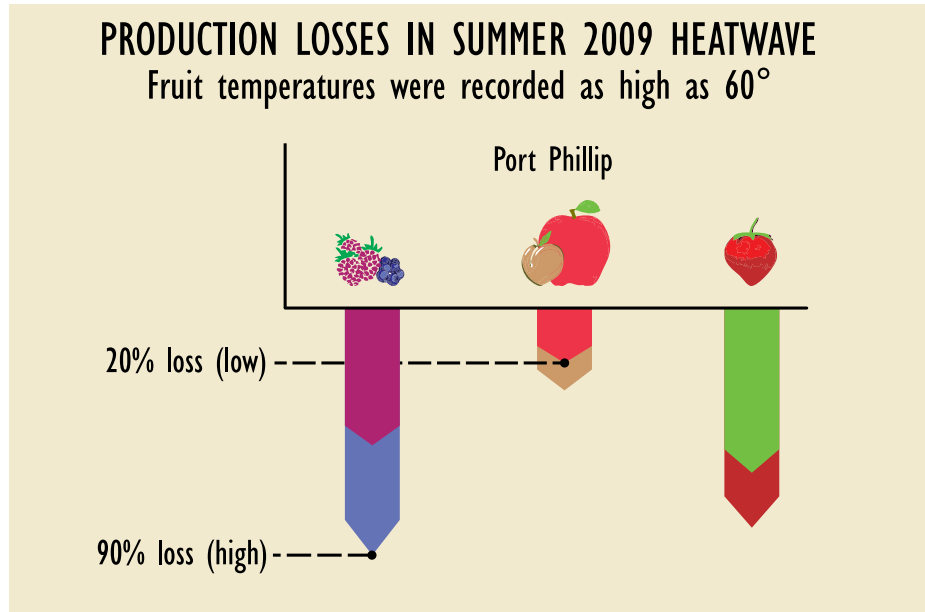
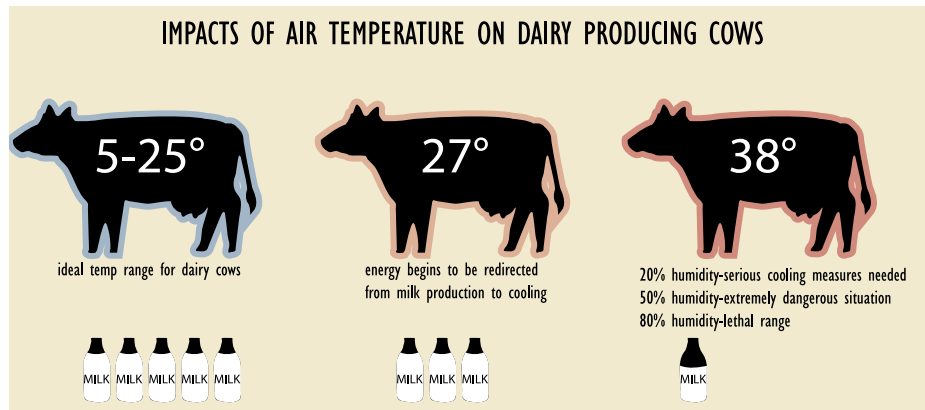


Figure 52:
CfES developed infographic.²⁶⁷



Victorian agriculture comprises cropping, beef and dairy, wool production, and a complex array of horticulture. Agriculture is worth billions of dollars to the Victorian economy and is vital for regional communities.

Heatwave intervention – livestock

Heat impacts on livestock performance, health and welfare is becoming a serious issue especially for Australian dairy farmers.²⁶⁸ The effects of heat stress include a drop in milk production, reduced herd fertility and lower milk protein and fat tests. It can also trigger weight losses and create health problems (Figure 51).

Simple steps like shade and water provision in farm management practice are important for animal welfare and livestock production. Livestock production increases when they have access to shade.²⁶⁹ Other agriculture management intervention methods for heatwaves include; changes to milking times, access to cool drinking water at all times, changes to paddock rotation, developing a summer nutrition program and altering mating management.²⁷⁰

Heatwave intervention – horticulture and viticulture

Crop production in Victoria includes the grain industry (wheat, barley, canola, field peas and other grains), the horticulture and viticulture industries (vegetables, fruit – particularly pome fruit, citrus, stone fruit and berries, nuts and grapes).

Extreme heat can cause crops such as wheat to age faster and reduce yields.²⁷¹

Increases in heatwaves present challenges for growing crops in Victoria. Heatwave impacts from the Victorian 2009 heatwaves included fruit that was downgraded because of reduced storage-life and a smaller size and substantial product loss in the pear and apple industries (Figure 50).²⁷² On 7 February 2009 temperatures reached 46.1°C at Shepparton in the Goulburn Valley, Victoria. Growers reported losses due to apple sunburn of 30 – 70%, and some crops were not even harvested in the Goulburn Valley. Flesh of the worst affected fruit turned soft, while other fruit had sunburn patches on those surfaces most exposed to sunlight. Damage was greatest on sun-exposed fruit, where fruit temperatures of up to 60°C were recorded.

Estimates of losses in viticulture during the 2009 South-East Australian heatwave, were not always related just to the heat exceeding certain thresholds. Management practices employed in the lead up and through the event also played a part.²⁷³ Encouraging management approaches such as good canopy growth and shading of potentially exposed fruit, is important in reducing heat damage.²⁷⁴

Cooling centres may provide residents with air-conditioning, shade and/ or water, located at various places like community centres, libraries or unoccupied schools during summer.

6.3 Innovation and development

People-centred

Heatwaves can affect anyone. Heat related illness can range in severity, from mild conditions such as rash or cramps to more serious and life threatening ones such as heat stroke. Heatwaves can also exacerbate pre existing medical conditions such as heart disease. Ensuring the community is informed, supported and protected from the health impact of extreme heat will minimise the health impacts of these events.

Without appropriate knowledge, planning, preparation and resources, people, especially those most vulnerable, put their physical and psychological health, and potentially their lives at risk.

Heatwave intervention methods include heat health alerts and education, cooling centres, building retrofits, cool roofs and urban forests.

Heat health alerts

The Victorian Heat Health Alert System (HHAS) notifies internal and external stakeholders of forecast heatwave conditions which are likely to impact on human health.²⁷⁵ Heat health alerts are activated when forecast temperatures from the Bureau of Meteorology are indicated to exceed a heat health temperature threshold or over prolonged consecutive periods of excess heat as this can still impact on health and community services. Heat health thresholds in northern Victoria are higher than heat health thresholds in the southern part of Victoria.

An alert can be issued statewide or district specific. The alerts contain information on when the temperature is forecast to exceed the threshold and the district the alert is based on. It is then expected that internal and external stakeholders respond in accordance with local heatwave plans and operational protocols to ensure safe service provision and business continuity.

The alert is sent by Victoria's Chief Health Officer via email and is also made available on the Chief Health Officer's website. The broader community can apply to receive a Really Simple Syndication (RSS) feed from the Chief Health Officer's website or heat health information via the Better Health Channel free iPhone application.²⁷⁶

Municipal councils in Victoria have developed local Heatwave Plans. The department provides resources such as the *Heatwave Planning Guide* and the *Heatwave plan review tool* to assist local councils. Most plans sit with the council Municipal Public Health Plan.

Cooling centres

Cooling centres provide an environment for residents to retreat from the heat. Cooling centres may provide residents with air-conditioning, shade and/ or water, located at various places like community centres, libraries or unoccupied schools during summer. Across Victoria a number of cooling centres have been allocated or trialled.

Beechworth Health Service has established a series of 'Cool Relief' centres across Beechworth, Yackandandah and Tangambalanga and it is anticipated that the concept will extend across the Indigo Shire.

Retrofits providing natural ventilation

In Moreland, the Kinda Cooling project is an initiative from the Moreland Energy Foundation Limited to make kindergarten buildings more comfortable, particularly in summer, using blinds on north-facing windows, fans, cross ventilation and night purging. This design reduces the reliance of air-conditioning, and is a critical step to avoid heat stress impacts associated with electricity blackouts in heatwaves (refer to the Infrastructure chapter). The retrofit is more energy-efficient and cost-saving for the community-run kindergarten than the alternative of installing an air-conditioner with high capital and on-going energy costs while also providing the benefits of a cool environment for the children during heatwaves.

Urban-centred: Cool roofs

A cool roof is one that reflects heat and emits absorbed radiation at a higher rate than standard materials.²⁷⁷ Cool roof or white roof projects as they are also known – because of the white solar-reflective paint used – are becoming more popular and adopted internationally because of the many benefits they provide in reducing the heat absorption of buildings. The benefits of cool roofs include reducing the community's urban heat island effect, lower maintenance and use of air-conditioning thus reducing electricity bills and amongst other benefits cool roofs keep buildings cooler and at a more constant temperature – reducing human heat health stresses.

The Moreland kindergartens retrofit included the painting of its large tin roof with a heat reflective paint to reduce heat absorption in the building. The cool roof has contributed to the overall benefits of the retrofit. The ArtPlay building at Birrarung Marr has taken steps to reduce building heat through painting its roof white. The ArtPlay building cool roof has meant children are not sent home because it's too hot in the building and has contributed to programs being able to be run longer, benefiting the people who occupy the building.²⁷⁸

Urban forests

Urban forests are a key contributor to quality urban environments providing shade through canopy cover, improving air quality, reducing the urban heat island effect, improving biodiversity and aesthetics of the urban environment.

To future proof Melbourne's western suburbs from the urban heat island effect during the day, an urban forest project called Greening the West has been developed by City West Water. With Melbourne's western suburbs being generally hotter and drier than the rest of the city and its community being poorer in health, this project aims to minimise the urban heat island effect, improve air quality, improve the environment and health status of Melbourne's west through increasing vegetation and tree canopy cover through its suburbs.

Cool roof or white roof projects as they are also known – because of the white solar-reflective paint used – are becoming more popular and adopted internationally because of the many benefits they provide in reducing the heat absorption of buildings.

Under construction in Milan, Italy is Bosco Verticale, the world's first vertical forest, an apartment tower, with each apartment having a balcony planted with trees.

The City of Melbourne has developed the *Urban Forest Strategy* to reduce the impact of the urban heat island effect. The *Urban Forest Strategy* aims to use trees and vegetation to reduce city temperatures, day and night. The council's draft *Urban Forest Strategy* and draft *Open Space Strategy* will ensure healthier, greener and more resilient landscapes and open spaces over the next 100 years. Following more than a decade of drought, severe water restrictions and periods of extreme heat, combined with an ageing tree stock, the city's trees were under immense stress and many were in a state of accelerated decline.²⁷⁹ This has been addressed.

Under construction in Milan, Italy is Bosco Verticale, the world's first vertical forest, an apartment tower, with each apartment having a balcony planted with trees (Figure 53). In the summer, the trees will shade the windows and filter the city's dust and in the winter, sunlight will shine through the bare branches. The architect, Stefano Boeri says that building such a tower adds only 5% to construction costs. The architect notes that if the units were to be constructed unstacked as stand-alone units across a single surface, the project would require 50,000 square meters of land, and 10,000 square meters of woodland.²⁸⁰

Figure 53:
Bosco Verticale, Milan.²⁸¹



In the *Living Melbourne, Living Victoria Roadmap* developed by the Living Victoria Ministerial Advisory Council, the council proposed a vision as a starting point for improving water resources management which would contribute to a more liveable, sustainable and productive Melbourne.

The council noted that water management plays an important role in underpinning the vitality and prosperity of the city through, amongst other things, supporting green landscapes that significantly enhance urban amenity and help to combat the impacts of the urban heat island effect. Further linkages between urban water management and urban liveability were also addressed by the council.²⁸²

CONCLUSION

I began this paper with a list of recent highly authoritative commentaries about climate change, its impacts, and our role in its production. This **Climate Change Foundation Paper** adds to the expanding range of reports on climate change issues.

Concerns about climate change are firming. They are not evaporating. We are tracking at the higher end of earlier projections.

In Australia we are vulnerable. In Victoria our seaboard, our biodiversity, our infrastructure are all at risk. Native species and agricultural production are both exposed. The risk of extreme events is elevated.

Impacts cascade and compound. We have described such scenarios in this **paper**. To read them is to be deeply concerned.

Calls have been made for “aggressive” intervention. The situation we confront clearly warrants such a response across all tiers of government, industry sectors and the broader community.

In accordance with the legislation which guides my office, recommendations will be made in the **State of the Environment Report**.

Concerns about climate change are firming.
They are not evaporating.

ENDNOTES

- 1 State of the Climate 2012 CSIRO and the Bureau of Meteorology, Australian Government
- 2 Report on Climate Change and Greenhouse Gas Emissions in Victoria, Victorian Government Department of Sustainability and Environment Melbourne, March 2012
- 3 <http://www.theage.com.au/opinion/society-and-culture/here-comes-the-sun-chilling-verdict-on-a-climate-going-to-extremes-20120806-23q5o.html> accessed 8 Aug 2012
- 4 *We have nothing to lose* Prof. Dr. Dr. Peter Höpfe MUNICH RE Topics Geo Natural catastrophes 2010, Analyses, assessments, positions, 2011
- 5 *Many Publics: Participation, Inventiveness and Change*, Commissioner of Environmental Sustainability, State of Victoria, April 2012
- 6 Science Policy People, State of the Environment Reporting 2013, Victoria, (2010) Commissioner for Environmental Sustainability, State of Victoria
- 7 *Commissioner for Environmental Sustainability Act 2003*
- 8 State of the Climate March 2010 and State of the Climate 2012 CSIRO and the Bureau of Meteorology, Australian Government
- 9 SEACI <http://www.seaci.org/publications/synthesis.html>
- 10 Australia State of the Environment 2011, Australian Government, Department of Sustainability, environment, Water, Population and Communities
- 11 Low Carbon Growth Plan for Australia, March 2010 and others ClimateWorks Australia
- 12 Global Climate Leadership Review 2012, The Climate Institute
- 13 OECD (2011) Towards Green Growth
- 14 http://e360.yale.edu/feature/ecological_corridors_connecting_fragmented_pockets_of_wildlife_habitat/2450/
- 15 Program for Climate Model Diagnosis and Intercomparison, <http://www-pcmdi.llnl.gov/about/index.php> retrieved 20 August 2012
- 16 IPCC, 2007: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller, eds.). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. http://unfccc.int/essential_background/convention/background/items/1349.php retrieved 9 August 2012
- 17 <http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-faqs.pdf> retrieved 9 August 2012
- 18 IPCC (2007) The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. FAQ 1.2 Figure 1. http://www.ipcc.ch/publications_and_data/ar4/wg1/en/faq-1-3-figure-1.html retrieved 14 August 2012
- 19 James Hansen, J., Sato, M. and Ruedy, R., 2012, 'Perception of climate change', *Proceedings of the National Academy of Sciences of the United States of America* www.pnas.org/cgi/doi/10.1073/pnas.1205276109
- 20 CSIRO, 2007, *Climate Change in Australia – Technical report 2007* Chapter 5
- 21 Anderson, K. and Bows A., 2011, Beyond dangerous climate change: emission scenarios for a new world. *Philosophical Transactions of the Royal Society A*, vol 369, pp 20-44
- 22 DSE, 2012, *Report on climate change and greenhouse gas emissions in Victoria. As required under Section 17 of the Climate Change Act 2010*, p 22
- 23 OECD, 2012, *OECD Environmental Outlook to 2050: The Consequences of Inaction*, OECD Publishing. doi: 10.1787/9789264122246-en
- 24 WMO, 2011, *Greenhouse Gas Bulletin No. 7* <http://www.wmo.int/pages/prog/arep/gaw/ghg/GHGbulletin.html> retrieved 19 October 2012
- 25 OECD, 2011. The OECD Environmental Outlook to 2050, Key findings on climate change. http://www.oecd.org/document/11/0,3746,en_2649_37465_49036555_1_1_1_37465,00.html retrieved 19 October 2012
- 26 IPCC, 1995, *Climate Change 1995, The Science of Climate Change: Summary for Policymakers and Technical Summary of the Working Group I Report*, p 22.
- 27 <http://www.climatechange.gov.au/climate-change/emissions.aspx>

- 28 IPCC, 2000. *Emissions Scenarios*. Nakicenovic, N and Swart, R., eds., Cambridge University Press, UK
- 29 Raupach M.R., Marland, G., Ciais, P., Le Quéré, C., Canadell, J.G., Klepper, G., and Field, C.B., 2007, 'Global and regional drivers of accelerating CO₂ emissions' *Proceedings of the National Academy of Sciences of the United States of America*, vol104, pp10288-10293; Raupach, M.R. and Canadell, J.G., 2010, 'Carbon and the Anthropocene' *Current Opinion in Environmental Sustainability*, col4:doi:10.1016/j.cosust.2010.04.003; GCP, 2011, 'Global carbon budget' *Global Carbon Project*, <http://www.globalcarbonproject.org/carbonbudget/index.htm>. retrieved 15 August2012
- 30 Data provided by CSIRO using method described in: Watterson, I. G., 2008, Calculation of probability density functions for temperature and precipitation change under global warming. *Journal of Geophysical Research*, vol 113, D12106, doi:10.1029/2007JD009254.
- 31 IPCC, 2007: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M. Averyt, K.B., Tignor, M. and Miller, H.L., eds.). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. Figure 10.28.
- 32 IPCC, 2007, Impacts, Adaptation and Vulnerability, Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. (Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden, P.J., and Hanson, C.E., eds) Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. Figure 11.4; modified by CSIRO (2010) *Adaptation science: Opportunities and responses to climate change impacts*.
- 33 Wu, L., Cai, W., Zhang, L., Nakamura, H., Timmermann, A., Joyce, T., McPhaden, M.J., Alexander, M., Qiu, B., Visbeck, M., Chang, P. and Giese, B., 2012, 'Enhanced warming over the global subtropical western boundary currents' *Nature Climate Change*, vol 2, pp161-166
- 34 CSIRO and BoM, 2012, *State of the Climate*
- 35 Data provided by CSIRO using method described in: Watterson, I. G., 2008, Calculation of probability density functions for temperature and precipitation change under global warming. *Journal of Geophysical Research*, vol 113, D12106, doi:10.1029/2007JD009254.
- 36 CSIRO, 2007, *Climate Change in Australia – Technical Report*, Chapter 5.
- 37 Bureau of Meteorology; Comrie, N., 2011, *Review of the 2010-11 Flood Warnings and Response*, Victorian Government; Stephenson, C., 2010, *The impacts, losses and benefits sustained from five severe bushfires in south-eastern Australia. Fire and Adaptive Management Report No. 88*. Bushfire Cooperative Research Centre; Victorian Government Department of Human Services, 2009, *January 2009 Heatwave in Victoria: An Assessment of Health Impacts*
- 38 South Eastern Australian Climate Initiative http://www.seaci.org/publications/documents/SEACI-2Reports/SEACI2_Factsheet2of4_WEB_110714.pdf retrieved 16 October 2012
- 39 South Eastern Australian Climate Initiative http://www.seaci.org/publications/documents/SEACI-2Reports/SEACI2_Factsheet2of4_WEB_110714.pdf retrieved 16 October 2012
- 40 Nicholls, N., 2011, 'What caused the eastern Australia heavy rains and floods of 2010/11?'; *Bulletin of the Australian Meteorological and Oceanographic Society*, vol.24. p 34
- 41 Climate Commission, 2012, *The Science behind southeast Australia's wet, cool summer*
- 42 Pall, P., Aina, T., Stone, D.A., Stott, P.A., Nozawa, T., Hilberts, A.G.J., Lohmann, D. and Allen, M.R., 2011, 'Anthropogenic greenhouse gas contribution to flood risk in England and Wales in autumn 2000', *Nature*, vol 470, 382-386
- 43 IPCC, 2012: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (Field, C.B., Barros, V., Stocker, T.F., Qin, D., Dokken, D.J., Ebi, K.L., Mastrandrea, M.D., Mach, K.J., Plattner, G.-K., Allen, S.K., Tignor, M. and Midgley, P.M.eds.). Cambridge University Press, Cambridge, UK, and New York, NY, USA
- 44 Munich Re, 2012, *Topic GEO Natural catastrophes 2011Analyses, assessments, positions*
- 45 Koppen, W., 2011, The thermal zones of the Earth according to the duration of hot, moderate and cold periods and to the impact of heat on the organic world. *Meteorologische Zeitschrift*, vol 20, pp. 351-360(10)
- 46 Stern, H., De Hoedt, G. & Ernst, J., 2000, Objective classification of Australian climates *Australian Meteorology Magazine*, vol 49, pp 87-96
- 47 NOAA Celebrates 200 years of science, service and stewardship <http://celebrating200years.noaa.gov/> retrieved 19 October 2012

- 48 Data provided from the Coupled Model Intercomparison project (CMIP3), processed by CSIRO
- 49 Dunlop, M., and Brown, P.R., 2008, *Implications of climate change for Australia's National Reserve System: A preliminary assessment* Report to the Department of Climate Change, February 2008. Department of Climate Change, Canberra, Australia.
- 50 Berreton, R., Bennet, S. and Manseergh, I, 1995, Enhanced greenhouse climate change and its Potential effect on selected fauna of south-eastern Australia: a trend analysis. *Biological Conservation*, vol 12, pp 339-354
- 51 Whetton, P., Karoly, D., Watterson, I., Webb, L., Drost, F., Kirono, D. and McInnes, K. 2011, *Australian climate at four degrees or more of global warming* Presented at *Four Degrees or More?* Conference, Melbourne, 12-14 July 2011
- 52 State of the Environment 2011 Committee, *Australia State of the Environment 2011*, Independent report to the Australian Government Minister for Sustainability, Environment, Water, Population and Communities, Canberra, DSEWPac, 2011
- 53 Driscoll D.A., Felton, A., Gibbons, P., Felton, A.M., Munro, N.T., and Lindenmayer, D.B., 2011, *Priorities in policy and management when existing biodiversity stressors interact with climate-change*. In press.
- 54 Climate Commission, 2011, *The critical decade: Climate science risks and responses*. Climate Commission Secretariate, Department of Climate Change and Energy Efficiency, Canberra
- 55 Steffen, W., Burbidge, A.A., Hughes, L., Kitching, R., Lindenmayer, D., Musgrave, W., Stafford Smith, M. and Werner, P.A., 2009, *Australia's Biodiversity and Climate Change: a strategic assessment of the vulnerability of Australia's biodiversity to climate change*, CSIRO Publishing, Australia.
- 56 CES (2008). State of the Environment Victoria 2008. Commissioner for Environmental Sustainability, Victoria.
- 57 Australian Bureau of Statistics, 2010, *Australia's Environment: Issues and Trends 2010*, ABS Catalogue No. 4613.0, Australian Bureau of Statistics, Canberra; Booth, D., Edgar, G., Figueira, W., Jenkins, G., Kingsford, M., Lenanton, R. and Thresher, R., 2009, 'Temperate Coastal and Demersal Fish and Climate Change', in Poloczanska, E.S., Hobday, A.J., and Richardson, A.J., eds., *Marine Climate Change Impacts and Adaptation Report Card for Australia 2009*, NCCARF Publication 05/09; Burrows, M.T., Schoeman, D.S., Buckley, L.B. et al., 2011, 'The pace of shifting climate in marine and terrestrial ecosystems', *Science*, 334 (6056); Chambers L.E., Congdon B.C., Dunlop N., Dann P. and Devney C., 2009, 'Seabirds', in Poloczanska, E.S., Hobday, A.J., and Richardson, A.J., eds., *Marine Climate Change Impacts and Adaptation Report Card for Australia 2009*, NCCARF Publication 05/09; Chessman, B., 2009, 'Climatic changes and 13-year trends in stream macroinvertebrate assemblages in New South Wales, Australia', *Global Change Biology* (2009) 15, pp. 2791 – 2802; Climate Commission, 2011, *The critical decade: Climate science risks and responses*. Climate Commission Secretariate, Department of Climate Change and Energy Efficiency, Canberra; CSIRO, 2011, *Climate Change: Science and Solutions for Australia*, Cleugh, H., Stafford Smith, M., Battaglia, M. and Graham, P. eds, CSIRO Publishing; Department of Climate Change, 2009, *Australia's biodiversity and climate change: A strategic assessment of the vulnerability of Australia's biodiversity to climate change. Summary for policy makers 2009*, Summary of a report to the Natural Resource Management Ministerial Council commissioned by the Australian Government. Department of Climate Change, Canberra; Department of Sustainability Environment, 2007, *Climate Change in Victoria: A Summary*, Department of Sustainability and Environment, Melbourne; Edmunds, M., Mustoe, S., Stewart, K., Sheedy, E. and Ong, J., 2009, *VNPA Nature Conservation Review: Marine Conservation Priorities and Issues for Victoria*. Report to Victorian National Parks Association. Australian Marine Ecology Report 405, Melbourne; Hobday A.J., Griffiths S. and Ward T., 2009, 'Pelagic Fishes and Sharks', in Poloczanska, E.S., Hobday, A.J., and Richardson, A.J., eds., *Marine Climate Change Impacts and Adaptation Report Card for Australia 2009*, NCCARF Publication 05/09; Howard W.R., Havenhand J., Parker L., Raftos D., Ross, P., Williamson J. and Matear R., 2009, 'Ocean acidification', in Poloczanska, E.S., Hobday, A.J., and Richardson, A.J., eds., *Marine Climate Change Impacts and Adaptation Report Card for Australia 2009*, NCCARF Publication 05/09; Hughes, L., Cawsey, E.M., and Westoby, M., 1996, 'Climatic range sizes of Eucalyptus species in relation to future climate change', *Global Ecology and Biogeography Letters* 5, pp. 23 – 29; Kingsford, R.T., 2011, 'Conservation management of rivers and wetlands under climate change – a synthesis', *Marine and Freshwater Research* 62(3), pp. 217-222; Koehn J.D., Hobday, A.J., Pratchett, M.S. and Gillanders, B.M., 2011, 'Climate change and Australian marine and freshwater environments, fishes and fisheries: synthesis and options for adaptation', *Marine and Freshwater Research* 62, pp. 1148-1164; Leahy, P., Robinson, D., Patten, R., and Kramer, A., 2010, *Lakes in the Western District of Victoria and Climate Change*, Environment Protection Authority Victoria; Lough J.M. and Hobday A.J., 2011, 'Observed climate change in Australian marine and freshwater environments', *Marine and Freshwater Research*, 2011, 62, pp. 984–999; Nicholls, N., 2005,

- 'Climate variability, climate change and the Australian snow season', *Australian Meteorological Magazine*, 54, pp. 177-185; Poloczanska E.S., Babcock R.C., Butler A., Hobday A.J., Hoegh-Guldberg O., Kunz T.J., Matear R., Milton D., Okey T.A. and Richardson A.J., 2007, 'Climate Change and Australian Marine Life', *Oceanography and Marine Biology Annual Review* 45, pp. 409-480; Poloczanska, E.S., Hobday, A.J., and Richardson, A.J., eds., *Marine Climate Change Impacts and Adaptation Report Card for Australia 2009*, NCCARF Publication 05/09; Richardson A.J., Hobday, A.J. and Poloczanska E.S., 2009, 'Australia's Marine Life', in Poloczanska, E.S., Hobday, A.J., and Richardson, A.J., eds., *Marine Climate Change Impacts and Adaptation Report Card for Australia 2009*, NCCARF Publication 05/09; Victorian Coastal Council, 2006, *Emerging Scientific Issues on Victoria's Coast Science Panel Victorian Coastal Council*, August 2006; Victorian Coastal Council, 2011, *Emerging Scientific Issues on Victoria's Coast 2011: Update*, Victorian Coastal Council Science Panel October 2011; Victorian National Parks Association, 2010, *Protecting our seas and shores – Priorities for marine conservation in Victoria*, Victorian National Parks Association; Wernberg, T., Russell, B.D., Moore, P.J., Ling, S.D., Smale, D.A., Campbell, A., Coleman, M.A., Steinberg, P.D., Kendrick, G.A., Connell, S.D., 2011, 'Impacts of climate change in a global hotspot for temperate marine biodiversity and ocean warming', *Journal of Experimental Marine Biology and Ecology* 400 (2011), pp. 7-16; Wernberg, T., Russell, B.D., Thomsen, M.S., Gurgel, C.F.D., Bradshaw, C.J.A., Poloczanska, E.S., Connell, S.D., 2011, 'Seaweed communities in retreat from ocean warming', *Current Biology*, 21, pp. 1828-1832
- 58 Australian Bureau of Statistics, 2010, *Australia's Environment: Issues and Trends 2010*, ABS Catalogue No. 4613.0, Australian Bureau of Statistics, Canberra; Booth, D., Edgar, G., Figueira, W., Jenkins, G., Kingsford, M., Lenanton, R. and Thresher, R., 2009, 'Temperate Coastal and Demersal Fish and Climate Change' in Poloczanska, E.S., Hobday, A.J., and Richardson, A.J., eds., *Marine Climate Change Impacts and Adaptation Report Card for Australia 2009*, NCCARF Publication 05/09; CSIRO, 2011, *Climate Change: Science and Solutions for Australia*, Cleugh, H., Stafford Smith, M., Battaglia, M. and Graham, P. eds, CSIRO Publishing; Department of Primary Industries, 2009, *South-Eastern Australia Program: Adaptation of fishing and aquaculture sectors and fisheries management to climate change in South-Eastern Australia program plan*, Department of Primary Industries, Victoria; Department of Sustainability Environment, 2007, *Climate Change in Victoria: A Summary*, Department of Sustainability and Environment, Melbourne; Hobday, A.J., Poloczanska, E.S., Matear, R.J., eds., 2008, *Implications of Climate Change for Australian Fisheries and Aquaculture: a preliminary assessment*, Department of Climate Change; Koehn J.D., Hobday, A.J., Pratchett, M.S. and Gillanders, B.M., 2011, 'Climate change and Australian marine and freshwater environments, fishes and fisheries: synthesis and options for adaptation', *Marine and Freshwater Research* 62, pp. 1148-1164; Sands, A., 2011, *Fisheries and climate change: potential challenges and opportunities for Commonwealth fisheries*, ABARES technical report 11.1, Canberra
- 59 Victorian National Parks Association, 2010, *Protecting our seas and shores – Priorities for marine conservation in Victoria*. Victorian National Parks Association.
- 60 Victorian Auditor-General (2011). *Environmental Management of Marine Protected Areas. Victorian Auditor-General's Report*. Victorian Auditor-General's Office; Department of Primary Industries, 2011, *Annual report 2010-11*, Department of Primary Industries, Victoria
- 61 Bureau of Meteorology, 2012, *State of the Climate 2012*. Bureau of Meteorology, Australian Government
- 62 Wernberg, T., Russell, B.D., Moore, P.J., Ling, S.D., Smale, D.A., Campbell, A., Coleman, M.A., Steinberg, P.D., Kendrick, G.A., Connell, S.D., 2011, 'Impacts of climate change in a global hotspot for temperate marine biodiversity and ocean warming', *Journal of Experimental Marine Biology and Ecology*, 400, pp. 7-16; Poloczanska, E.S., Hobday, A.J., and Richardson, A.J., eds., 2009, *Marine climate change: impacts and adaptation report card for Australia 2009*, National Climate Change Adaptation Research Facility Publication 05/09.
- 63 Booth, D., Edgar, G., Figueira, W., Jenkins, G., Kingsford, M., Lenanton, R. and Thresher, R., 2009, 'Temperate Coastal and Demersal Fish and Climate Change', in Poloczanska, E.S., Hobday, A.J., and Richardson, A.J., eds., *A Marine Climate Change Impacts and Adaptation Report Card for Australia 2009*, NCCARF Publication 05/09.
- 64 Department of Primary Industries, 2009, *South-Eastern Australia Program: Adaptation of fishing and aquaculture sectors and fisheries management to climate change in South-Eastern Australia, program plan*, Department of Primary Industries, Victoria
- 65 Lough J.M. and Hobday A.J., 2011, 'Observed climate change in Australian marine and freshwater environments', *Marine and Freshwater Research*, 2011, 62, pp. 984-999
- 66 Wernberg, T., Russell, B.D., Moore, P.J., Ling, S.D., Smale, D.A., Campbell, A., Coleman, M.A., Steinberg, P.D., Kendrick, G.A., Connell, S.D., 2011, 'Impacts of climate change in a global hotspot for temperate marine biodiversity and ocean warming', *Journal of Experimental Marine Biology and Ecology*, 400 (2011), pp. 7-16

- 67 Department of Primary Industries, 2009, *South-Eastern Australia Program: Adaptation of fishing and aquaculture sectors and fisheries management to climate change in South-Eastern Australia, program plan*. Department of Primary Industries, Victoria; Lough J.M. and Hobday A.J., 2011, 'Observed climate change in Australian marine and freshwater environments' *Marine and Freshwater Research*, 2011, 62, pp. 984–999; Wernberg, T., Russell, B.D., Moore, P.J., Ling, S.D., Smale, D.A., Campbell, A., Coleman, M.A., Steinberg, P.D., Kendrick, G.A., Connell, S.D., 2011, 'Impacts of climate change in a global hotspot for temperate marine biodiversity and ocean warming', *Journal of Experimental Marine Biology and Ecology*, 400 (2011), pp. 7–16
- 68 Richardson A.J., Hobday, A.J. and Poloczanska E.S., 2009, 'Australia's Marine Life' in Poloczanska, E.S., Hobday, A.J., and Richardson, A.J., eds., *A Marine Climate Change Impacts and Adaptation Report Card for Australia 2009*, NCCARF Publication 05/09; Wormworth, J. and Sekercioglu, C.H., 2011, *Winged Sentinels Birds and Climate Change*, Cambridge University Press, New York
- 69 Burrows, M.T., et al. 2011, 'The pace of shifting climate in marine and terrestrial ecosystems', *Science*, 334 no. 6056, pp. 652-655
- 70 Poloczanska E.S., Babcock R.C., Butler A., Hobday A.J., Hoegh-Guldberg O., Kunz T.J., Matear R., Milton D., Okey T.A. and Richardson A.J., 2007, 'Climate Change and Australian Marine Life', *Oceanography and Marine Biology Annual Review* 45, pp. 409-480; Wernberg, T., Russell, B.D., Moore, P.J., Ling, S.D., Smale, D.A., Campbell, A., Coleman, M.A., Steinberg, P.D., Kendrick, G.A., Connell, S.D., 2011, 'Impacts of climate change in a global hotspot for temperate marine biodiversity and ocean warming', *Journal of Experimental Marine Biology and Ecology* 400, pp. 7–16
- 71 Richardson A.J., Hobday, A.J. and Poloczanska E.S., 2009, 'Australia's Marine Life', in Poloczanska, E.S., Hobday, A.J., and Richardson, A.J. eds., *Report Card of Marine Climate Change for Australia 2009*, NCCARF Publication 05/09.
- 72 Wernberg, T., Russell, B.D., Thomsen, M.S., Gurgel, C.F.D., Bradshaw, C.J.A., Poloczanska, E.S., Connell, S.D., 2011, 'Seaweed communities in retreat from ocean warming', *Current Biology*, 21, pp. 1828-1832
- 73 Wernberg, T., Russell, B.D., Moore, P.J., Ling, S.D., Smale, D.A., Campbell, A., Coleman, M.A., Steinberg, P.D., Kendrick, G.A., Connell, S.D., 2011, 'Impacts of climate change in a global hotspot for temperate marine biodiversity and ocean warming', *Journal of Experimental Marine Biology and Ecology* 400 (2011), pp. 7–16
- 74 Hobday, A.J., Poloczanska, E.S., and Matear, R.J., eds., 2008, *Implications of Climate Change for Australian Fisheries and Aquaculture: a preliminary assessment*. Department of Climate Change; Wernberg, T., Russell, B.D., Moore, P.J., Ling, S.D., Smale, D.A., Campbell, A., Coleman, M.A., Steinberg, P.D., Kendrick, G.A., Connell, S.D., 2011, 'Impacts of climate change in a global hotspot for temperate marine biodiversity and ocean warming', *Journal of Experimental Marine Biology and Ecology* 400 (2011), pp. 7–16
- 75 Booth, D., Edgar, G., Figueira, W., Jenkins, G., Kingsford, M., Lenanton, R. and Thresher, R., 2009, 'Temperate Coastal and Demersal Fish and Climate Change', in Poloczanska, E.S., Hobday, A.J., and Richardson, A.J., eds., *Marine Climate Change Impacts and Adaptation Report Card for Australia 2009*, NCCARF Publication 05/09
- 76 Nicholson, A.D., Jenkins, G., Sherwood, J. and Longmore, A., 2008, 'Physical environmental conditions, spawning and early-life stages of an estuarine fish: climate change implications for recruitment in intermittently open estuaries', *Marine and Freshwater Research* 59, pp. 735–749
- 77 Department of Sustainability and Environment, 2011, *Gippsland Region Sustainable Water Strategy*, Department of Sustainability and Environment
- 78 Booth, D., Edgar, G., Figueira, W., Jenkins, G., Kingsford, M., Lenanton, R. and Thresher, R., 2009, 'Temperate Coastal and Demersal Fish and Climate Change', in Poloczanska, E.S., Hobday, A.J., and Richardson, A.J., eds., *Marine Climate Change Impacts and Adaptation Report Card for Australia 2009*, NCCARF Publication 05/09
- 79 Department of Sustainability and Environment, 2011, *Gippsland Region Sustainable Water Strategy*, Department of Sustainability and Environment
- 80 Department of Primary Industries, 2009, *South-Eastern Australia Program: Adaptation of fishing and aquaculture sectors and fisheries management to climate change in South-Eastern Australia program plan*, Department of Primary Industries, Victoria; Booth, D., Edgar, G., Figueira, W., Jenkins, G., Kingsford, M., Lenanton, R. and Thresher, R., 2009, 'Temperate Coastal and Demersal Fish and Climate Change', in Poloczanska, E.S., Hobday, A.J., and Richardson, A.J., eds., *Marine Climate Change Impacts and Adaptation Report Card for Australia 2009*, NCCARF Publication 05/09; Sands, A., 2011, *Fisheries and climate change: potential challenges and opportunities for Commonwealth fisheries*, ABARES technical report 11.1, Canberra.

- 81 Alistair J. Hobday, Elvira S. Poloczanska, Richard J. Matear, eds., 2008, *Implications of Climate Change for Australian Fisheries and Aquaculture: a preliminary assessment*. Department of Climate Change
- 82 Hobday A.J., Griffiths S. and Ward T., 2009, 'Pelagic Fishes and Sharks', in Poloczanska, E.S., Hobday, A.J., and Richardson, A.J., eds., *Marine Climate Change Impacts and Adaptation Report Card for Australia 2009*, NCCARF Publication 05/09
- 83 Hobday, A.J., Poloczanska, E.S., Matear, R.J., eds., 2008, *Implications of Climate Change for Australian Fisheries and Aquaculture: a preliminary assessment*, Department of Climate Change
- 84 Booth, D., Edgar, G., Figueira, W., Jenkins, G., Kingsford, M., Lenanton, R. and Thresher, R., 2009, 'Temperate Coastal and Demersal Fish and Climate Change', in Poloczanska, E.S., Hobday, A.J., and Richardson, A.J., eds., *Marine Climate Change Impacts and Adaptation Report Card for Australia 2009*, NCCARF Publication 05/09; Richardson A.J., Hobday, A.J. and Poloczanska E.S. (2009) 'Australia's Marine Life', in Poloczanska, E.S., Hobday, A.J., and Richardson, A.J., eds., *Marine Climate Change Impacts and Adaptation Report Card for Australia 2009*, NCCARF Publication 05/09
- 85 Booth, D., Edgar, G., Figueira, W., Jenkins, G., Kingsford, M., Lenanton, R. and Thresher, R., 2009, 'Temperate Coastal and Demersal Fish and Climate Change', in Poloczanska, E.S., Hobday, A.J., and Richardson, A.J., eds., *Marine Climate Change Impacts and Adaptation Report Card for Australia 2009*, NCCARF Publication 05/09; Eadie, L. and Hoisington, C., 2011, *Stocking Up: Securing our marine economy*; Wernberg, T., Russell, B.D., Moore, P.J., Ling, S.D., Smale, D.A., Campbell, A., Coleman, M.A., Steinberg, P.D., Kendrick, G.A., Connell, S.D., 2011, 'Impacts of climate change in a global hotspot for temperate marine biodiversity and ocean warming', *Journal of Experimental Marine Biology and Ecology* 400 (2011), pp. 7–16
- 86 <http://www.usanpn.org/about/phenology/> retrieved 24 Sept 2012
- 87 CfES adapted from Stenseth N.C., and Mysterud, S., 2002, 'Climate, changing phenology, and other life history traits: Nonlinearity and match-mismatch to the environment', *Proceedings of the National Academy of Sciences* 99(21), pp. 13379-13381, National Academy of Sciences, USA
- 88 Based on an unpublished analysis by Lynda Chambers, Bureau of Meteorology, of the following literature - Keatley, M.R., Fletcher, T.D., Hudson, I.L., Ades, P.K., 2002, 'Phenological studies in Australia: potential application in historical and future climate analysis', *International Journal of Climatology* 22, pp. 1769-1780; Keatley, M.R., Hudson, I.L., 2007, 'Shift in flowering dates of Australian plants related to climate: 1983-2006'. MODSIM 2007, 10-13 December 2007, Christchurch, New Zealand; Chambers, L.E., Gibbs, H., Weston, M.A., 2008, 'Spatial and temporal variation in Masked Lapwing breeding', *Emu* 108, pp.115-124; Chambers, L.E., Quin, B., Menkhorst, P., Franklin, D., Smales, I., 2008, 'Climate as a driver for breeding in the Helmeted Honeyeater', *Emu* 108, pp. 15-22; Rumpff, L., Coates, F., Messina, A., Morgan, J., 2008, *Potential biological indicators of climate change: evidence from phenological records of plants along the Victorian coast*, Arthur Rylah Institute for Environmental Research Technical Report No. 175; Cullen, J.M., Chambers, L.E., Coutin, P.C., and Dann, P., 2009, 'Predicting the onset and success of breeding of Little Penguins, *Eudyptula minor*, on Phillip Island from ocean temperatures off south east Australia', *Marine Ecology Progress Series* 378, pp. 269-278; Gallagher, R.V, Hughes, L., Leishman, M.R., 2009, 'Phenological trends among Australian alpine species: using herbarium records to identify climate-change indicators', *Aust. J. Botany*, 57, pp. 1-9; Chambers, L.E., 2010, 'Altered avian seasonal movements in a peri-urban environment: climate related?', *Emu* 110, pp. 48-53; Chambers, L.E., and Keatley, M.R., 2010, 'Australian bird phenology – a search for climate signals', *Austral Ecology* 35, pp. 969-979; Gibbs, H., Chambers, L.E., Bennett, A.F., 2011, 'Temporal and spatial variability in breeding in Australian birds: potential implications of climate change', *Emu* 111, pp. 283-291
- 89 Petrie, P.R., Sadras, V.O., 2008, 'Advancement of grapevine maturity in Australia between 1993 and 2006: putative causes, magnitude of trends and viticultural consequences', *Australian Journal of Grape and Wine Research* 14, pp. 33-45; Webb, L. B., Whetton, P. H., and Barlow, E.W. R., 2011, 'Observed trends in winegrape maturity in Australia', *Global Change Biology* (2011), doi: 10.1111/j.1365-2486.2011.02434.x; Webb, L. B., Whetton, P. H., Bhend, J., Darbyshire, R., Briggs, P. R. and Barlow, E.W. R., 2012, 'Earlier wine-grape ripening driven by climatic warming and drying and management practices', *Nature Climate Change*, published online 26 February 2012 | DOI: 10.1038/NCLIMATE1417
- 90 Webb, L. B., Whetton, P. H., Bhend, J., Darbyshire, R., Briggs, P. R. and Barlow, E.W. R., 2012, 'Earlier wine-grape ripening driven by climatic warming and drying and management practices', *Nature Climate Change*, published online 26 February 2012 | DOI: 10.1038/NCLIMATE1417
- 91 Department of Sustainability and Environment, 2007, *Climate Change in Victoria: A Summary*, Department of Sustainability and Environment

- 92 Cullen, J.M., Chambers, L.E., Dann, P., Coutin, P.C., 2009, 'Predicting the onset and success of breeding of Little Penguins *Eudyptula minor*, on Phillip Island from ocean temperatures off south east Australia', *Marine Ecology Progress Series* 378, pp. 269-278; Chambers, L.E., Congdon, B.C., Devney, C., Dunlop, N., Woehler, E.J., Dann, P., 2011, 'Observed and predicted impacts of climate on Australian seabirds', *Emu* 111, pp. 235-251; Chambers, L.E., Dann, P., 2011, 'Seabirds and environmental change: understanding the impacts and increasing resilience', *ECOS online*, 7/11/2011 <http://www.ecomagazine.com/?paper=EC11093>; Chambers, L.E., Renwick, L., Dann, P., 2011, 'Climate, fire and Little Penguins', in Richardson, K., Steffen, W., and Liverman, D., eds, *Climate Change: Global Risks, Challenges and Decisions*, Cambridge University Press, pp 275-276;
- 93 <http://mesh.biology.washington.edu/penguinProject/Little/> retrieved 12 July 2012
- 94 Keatley M.R., Hudson I.L., 2007, 'A comparison of the long-term flowering patterns of Box-Ironbark species in Havelock and Rushworth forests', *Environmental Modeling and Assessment* 12, pp. 279-92; Mac Nally R., Bennett, A.F., Thomson, J.R., Radford, J.Q., Unmack, G., Horrocks, G., Vesk, P.A., 2009, 'Collapse of an avifauna: climate change appears to exacerbate habitat loss and degradation', *Biodiversity and Distributions* 15, pp. 720-30; Hudson, I.L., Keatley, M.R., Kang, I., 2010, 'Wavelet characterization of eucalypt flowering and the influence of climate', *Environmental and Ecological Statistics*, 18, pp. 513-533
- 95 Data provided by Department of Sustainability and Environment, Victoria, 2012
- 96 Booth, D., Edgar, G., Figueira, W., Jenkins, G., Kingsford, M., Lenanton, R. and Thresher, R., 2009, 'Temperate Coastal and Demersal Fish and Climate Change', in Poloczanska, E.S., Hobday, A.J., and Richardson, A.J., eds., *Marine Climate Change Impacts and Adaptation Report Card for Australia 2009*, NCCARF Publication 05/09; Victorian Coastal Council, 2011, *Emerging Scientific Issues on Victoria's Coast 2011: Update*, Victorian Coastal Council Science Panel October 2011
- 97 Data and material provided by Parks Victoria.
- 98 Edgar G. J. and Stuart-Smith R. D., 2009, 'Ecological effects of marine protected areas on rocky reef communities – a continental-scale analysis', *Marine Ecology Progress Series* vol 388; Koss, R. S., Miller, K., Wescott, G., Bellgrove, A., Boxshall, A., McBurnie, J., Bunce, A., Gilmour, P. and Ierodiaconou, D., 2009, 'An evaluation of Sea Search as a citizen science programme in Marine Protected Areas', *Pacific conservation biology*, 15, pp. 116-127
- 99 Herald Sun, 14 January 2011. Victorians brace for major floods as more rain forecast <http://www.heraldsun.com.au/ipad/victorians-brace-for-major-floods-as-more-rain-forecast/story-fn6bfmgc-1225987551876>
- 100 <http://www.bom.gov.au/climate/data/index.shtml>
- 101 The Age, 2 April 2011. Red arrows point to Grampians devastation www.theage.com.au/victoria/red-arrows-point-to-grampians-devastation-20110401-1crrf.html
- 102 <http://www.insurancecouncil.com.au/industry-statistics-data/disaster-statistics/historical-disaster-statistics> retrieved 18 October 2012; The Telegraph, 8 March 2010. Super storm and giant hailstones lash Melbourne <http://www.telegraph.co.uk/news/worldnews/australiaandthepacific/australia/7394608/Super-storm-and-giant-hailstones-lash-Melbourne.html>
- 103 Herald Sun, 7 Marc 2010. Storms hit Melbourne <http://www.heraldsun.com.au/news/huge-hailstorm-strikes-melbourne/story-e6fr7jo-1225837662827>
- 104 <http://www.seasprayslsc.com/flood-damage.html> retrieved 18 October 2012; Herald Sun, 10 July 2007. Surf club's a cliff hanger <http://www.heraldsun.com.au/news/victoria/surf-clubs-a-cliff-hanger/story-e6fr7kx-111113922748>
- 105 CSIRO, Maunsell Australia, Phillips Fox 2007, *Infrastructure and climate change risk assessment for Victoria: Report to the Victorian Government*
- 106 Infrastructure UK 2010, *National Infrastructure Plan 2010*, p 19
- 107 Engineering the Future 2011, *Infrastructure, Engineering and Climate change Adaptation – ensuring services in an uncertain future*, Royal Academy of Engineering, London, p 24
- 108 The information in these graphics has been compiled from a range of news articles of actual occurrences and assessments of projected risks. The need for greater research into cascading impacts from infrastructure failure, and how these are likely to be linked to extreme weather, has been identified by the National Climate Change Adaptation Research Facility: Thom B, Cane J, Cox R, Farrell C, Hayes P, Kay R, Kearns A, Low Choy D, McAneny J, McDonald J, Nolan M, Norman B, Nott J, Smith T, 2010: *National Climate Change Adaptation Research Plan for Settlements and Infrastructure*, National Climate Change Adaptation Research Facility, Gold Coast; p39

- 109 CSIRO 2010 *Change: Adapt now for the future* (<http://www.csiro.au/files/files/pxqa.pdf>); NCCARF 2010, *Impacts and adaptation responses of infrastructure and communities to heatwaves: the southern Australian experience of 2009*; Department of Primary Industries 2007, *16 January 2007 electricity supply interruptions in Victoria: what happened and why, and Opportunities and recommendations*.
- 110 UK Trade & Investment 2011, *Adapting to an Uncertain Climate: A World of Commercial Opportunities*
- 111 UK Trade & Investment 2011, *Adapting to an Uncertain Climate: A World of Commercial Opportunities*
- 112 Mercer 2012, *Through the looking glass: how investors are applying the results of the climate change scenarios study*
- 113 CSIRO 2011, *Climate Change: Science and Solutions for Australia*, CSIRO Publishing, Collingwood, p 65
- 114 Department of Defence, Australian Government, *Defence White Paper, 2009, Defending Australia in the Asia Pacific Century: Force 2030*
- 115 Australian Government 2010, *Critical Infrastructure Resilience Strategy*
- 116 <http://www.environment-agency.gov.uk/homeandleisure/floods/104695.aspx> retrieved 18 October 2012
- 117 Hallegatte, S., 2009, 'Strategies to adapt to uncertain climate change', *Global Environmental Change*, 19:240-247
- 118 Bliss, D.J., Neufield, R.D., and Ries, R.J. 2009, 'Storm Water Runoff Mitigation Using a Green Roof', *Environmental Engineering Science* 26(2): 407-418; Mentens, J., Raes, D. and Hermy, M. 2006 'Green roofs as a tool for solving the rainwater runoff problem in the urbanized 21st Century?', *Landscape and Urban Planning* 77: 217-226
- 119 Pedruco, P. and Watkinson R. 2010, *The impact of climate change on urban flooding in the Melbourne area using existing flood models*, Melbourne Water
- 120 City of Melbourne 2009, *City of Melbourne Climate Change Adaptation Strategy*, p 66
- 121 <http://www.pixelbuilding.com.au/FactSheet.pdf> retrieved 18 October 2012
- 122 <http://www.melbourne.vic.gov.au/Sustainability/CH2/aboutch2/Pages/Factsandfigures.aspx> retrieved 18 October 2012
- 123 http://e360.yale.edu/feature/green_architecture_building_retrofits_tap_energy_saving_potential/2461/ retrieved 18 October 2012
- 124 <http://www.hafencity.com/en/overview/hafencity-facts-and-figures.html> retrieved 18 October 2012 <http://www.worldchanging.com/archives/011536.html> retrieved 18 October 2012
- 125 http://www.dpcd.vic.gov.au/__data/assets/pdf_file/0003/41727/53-Managing-coastal-hazards-and-the-coastal-impacts-of-climate-change-PN53.pdf retrieved 12 Oct 2012
- 126 Department of Climate Change and Energy Efficiency 2010, *Developing a national coastal adaptation agenda: A report on the national climate change forum*, DCCEE, Canberra, p7
- 127 <http://www.defra.gov.uk/environment/climate/sectors/reporting-authorities/reporting-authorities-reports/> retrieved 18 October 2012
- 128 Population data comes from ABS; Electricity consumption data comes from Bureau of Resources and Energy Economics, <http://www.bree.gov.au/publications/aes-2012.html> <<http://www.bree.gov.au/publications/aes-2012.html>
- 129 Department of Resources, Energy and Tourism 2011, *Draft Energy White Paper: Strengthening the Foundations for Australia's Energy Future*, Commonwealth of Australia, Canberra, p 172
- 130 Australian Bureau of Statistics 2011, *Environmental issues: Energy Use and Conservation*, cat. no. 4602.0.55.001
- 131 <http://www.bom.gov.au/climate/data/>
- 132 <http://www.aemo.com.au/Electricity/Data/Price-and-Demand/Aggregated-Price-and-Demand-Data-Files/Aggregated-Price-and-Demand-2006-to-2010#2009> retrieved 19 October 2012
- 133 Australian Energy Market Operator 2011, *Victorian Annual Planning Report: Electricity and Gas Transmission Network Planning for Victoria*, p70
- 134 NCCARF 2010, *Impacts and adaptation responses of infrastructure and communities to heatwaves: the southern Australian experience of 2009*, p72

- 135 McGann, M. and Moss, J. 2010 *Smart Meters, Smart Justice? Energy, Poverty and the Smart Meter Rollout*, Social Justice Initiative, University of Melbourne
- 136 <http://www.climatechange.qld.gov.au/pdf/factsheets/1energy-b1.pdf> retrieved 28 November 2011
- 137 Department of Climate Change and Energy Efficiency 2011, *The Role of Regulation in Facilitating or Constraining Adaptation to Climate Change for Australian Infrastructure*, para 3.51.21
- 138 Australian Energy Market Commission 2011, *Strategic Priorities for Energy Market Development*, p 25
- 139 Australian Energy Regulator, press release 29 September 2011 'Regulator proposes changes to price setting rules'
- 140 Australian Energy Market Commission 2012, *Power of choice review - giving consumers options in the way they use electricity* (Final report); <http://www.aemc.gov.au/news/announcements/final-determination-made-on-network-regulation-rule-changes.html> <<http://www.aemc.gov.au/news/announcements/final-determination-made-on-network-regulation-rule-changes.html>
- 141 Commissioner for Environmental Sustainability Victoria, 2012, *Many Publics: Inventiveness, Participation and Change*
- 142 Pardeep and Aina, Stone, Stott, Nozawa, Hilberts, Lohmann, Allen, 2011, 'Anthropogenic greenhouse gas contribution to flood risk in England and Wales in autumn 2000' *Nature*, vol. 470; Zaffos, J., 2011, 'Extreme measures: The push to make climate research relevant' *The Daily Climate*, re-published in *Climate Spectator*
- 143 CSIRO 2011. *Climate variability, climate change and drought in eastern Australia*, factsheet, 22 January 2010, updated 14 October 2011
- 144 *ibid.*
- 145 CSIRO 2011. *Frequently asked questions about the causes of Australia's recent floods*, factsheet, 31 January 2010, updated 14 October 2011.
- 146 *ibid.*; IPCC, 2012: Summary for Policymakers. In: *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation* [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK, and New York, NY, USA, pp. 1-19.
- 147 CSIRO 22 January 2010, *op. cit.*
- 148 IPCC 2012, *op. cit.*
- 149 Department of Sustainability and Environment 2011, *Drought Management- Lessons for the Victorian Water Management Frameworks*, unpublished report
- 150 Gallant, A.J.E. and Karoly, D.J., 2010, 'A combined climate extremes index for the Australian region' *Journal of Climate*, 23: 6153–6165.
- 151 Gergis, J., Gallant, A.J.E., Braganza, K., Karoly, D.J., Allen, K., Cullen, L., D'Arrigo, R., Goodwin, I., Grierson, P., McGregor, S., 2011, 'On the long-term context of the 1997–2009 'Big Dry' in South-Eastern Australia: insights from a 206-year multi-proxy rainfall reconstruction', *Climatic Change*, 111: 923-944; Verdon-Kidd, D.C. and Kiem, A.S., 2009, 'Nature and causes of protracted droughts in southeast Australia: Comparison between the Federation, WWII, and Big Dry droughts' *Geophysical Research Letters*, 36, doi: 10.1029/2009GL041067
- 152 Department of Sustainability and Environment 2011, *op. cit.*
- 153 CSIRO, 22 January 2010, updated 14 October 2011. *Climate variability, climate change and drought in eastern Australia*, retrieved 19 October 2012, <http://www.csiro.au/Outcomes/Climate/Understanding/climate-and-drought-in-eastern-Australia.aspx>; CSIRO and Bureau of Meteorology, 2012, 'State of the Climate 2012'
- 154 Kirono, D.G.C., Kent, D.M., Hennessy, K.J., and Mpelasoka, F., 2011, 'Characteristics of Australian droughts under enhanced greenhouse conditions: Results from 14 global climate models', *Journal of Arid Environments*, 75: 566–575; Hennessy, K., Fawcett, R., Kirono, D., Mpelasoka, F., Jones, D., Bathols, J., Whetton, P., Stafford Smith, M., Howden, M., Mitchell, C. and Plummer, N., 2008a, 'An assessment of the impact of climate change on the nature and frequency of exceptional climatic events' Bureau of Meteorology and CSIRO; CSIRO, 2007-2012, *Climate change in Australia*, retrieved 19 October 2012, www.climatechangeinaustralia.gov.au/resources.php
- 155 Department of Primary Industries 2012, *Climate Challenges for Victorian Agriculture*, draft discussion paper, Future Farming Systems Research Division, Victoria Bureau of Rural Sciences 2008. *Wheat and sheep production in a changing climate: Western Victoria*. Communicating Climate Change Fact Sheet, August 2008.

- 156 Bureau of Rural Sciences 2008, *Wheat and sheep production in a changing climate: Western Victoria*, Communicating Climate Change, factsheet
- 157 Department of Sustainability and Environment 2011, op. cit. p. 40
- 158 *ibid.* p. 48
- 159 *ibid.* p. 60
- 160 *ibid.*
- 161 Department of Sustainability and Environment, Water Restrictions, retrieved 30 Nov 2011, <http://www.water.vic.gov.au/saving/restrictions>
- 162 Wimalasuriya, R et al, Rainfall Variability and its Impact on Dryland Cropping in Victoria, *52nd Annual Conference of the Australian Agricultural and Resource Economics Society (AARES)*, 2008
- 163 Van Rees, H., White, B., Laidlaw, J., McKinlay, D., 2011 'Farming during a period of extreme climate variability: consequences & lessons', final report prepared for the BCG as part of the project 'Developing climate change resilient cropping and mixed cropping/grazing businesses in Australia' supported by the Australian Government under its Climate Change Research Program
- 164 *ibid.*
- 165 Edwards, B., Gray, M., and Hunter, B., 2009, 'A Sunburnt Country: The Economic and Financial Impact of Drought on Rural and Regional Families in Australia in an Era of Climate Change', *Australian Journal of Labour Economics*, vol. 12:1, 109-131
- 166 Edwards, B., Gray, M., and Hunter, B., 2008, 'Social and economic impacts of drought on farm families and rural communities', *AIFS Submission into the Productivity Commission's Inquiry into Drought Support*
- 167 Fannin, B., 2011, 'Texas agricultural drought losses reach record \$5.2 billion', *AgriLife Today*, retrieved 19 October 2012, <http://agrilife.org/today/2011/08/17/texas-agricultural-drought-losses-reach-record-5-2-billion/>
- 168 Quiggin, J., 2010, *Drought, climate change and food prices in Australia*, Australian Conservation Foundation
- 169 ANZ Bank, *Economic Outlook – 15 October 2007*, www.anz.com/aus/corporate/EcoComm/Outlook.asp *ibid.*
- 170 VCOSS 2010, *Submission to the Victorian Rural and Regional Committees' Inquiry into the Extent and Nature of Disadvantage and Inequity in Rural and Regional*, Victoria
- 171 Walker, C., 2004, 'The Public Value of Urban Parks', *Beyond Recreation: A broader view of urban parks*, The Urban Institute
- 172 GHD 2007, 'Strategies for Managing Sports Surfaces in a Drier Climate', *Municipal Association of Victoria*; Driscoll, K. and Wood, L., 1999, 'Sporting Capital: Changes and challenges for rural communities in Victoria', *Centre for Applied Social Research RMIT*
- 173 National Rural Health Alliance Australia, 2009, *Suicide in rural Australia*, factsheet, retrieved 27 September 2011, <http://nrha.ruralhealth.org.au/cms/uploads/factsheets/fact-sheet-14-suicide.pdf>
- 174 The Climate Institute 2011, *A Climate of Suffering: Mental health and community wellbeing in the wake of extreme weather*
- 175 Barr, N., 2004, 'The Micro-Dynamics of Change in Australian Agriculture', *Australian Census Analytic Program*, Australian Bureau of Statistics
- 176 VCOSS 2010, op. cit.
- 177 Australian Institute of Family Studies 2011, *Migration, labour demand, housing markets and the drought in regional Australia*, Research Paper No 49
- 178 PMSEIC 2010, *Challenges at Energy-Water-Carbon Intersections*, Prime Minister's Science, Engineering and Innovation Council, Canberra
- 179 *ibid.*
- 180 Department of Sustainability and Environment 2011, op. cit.
- 181 CSIRO 31 January 2010, op. cit.; CSIRO and Bureau of Meteorology, 2012, op. cit.
- 182 Nichols, N., 2011, 'What caused the eastern Australia heavy rains and floods of 2010/11?', *President's Column in Bulletin of the Australian Meteorological and Oceanographic Society*, vol.24 p. 33; Bureau of Meteorology, 2012, *Exceptional rainfall across southeast Australia*, Special Climate Statement 39

- 183 Bureau of Meteorology, 2012, Special Climate Statement 39 op. cit.; McBride, J.L. and Nicholls, N., 1983, 'Seasonal relationships between Australian rainfall and the Southern Oscillation', *Mon Weath Rev.*, 111, 1998–2004; CSIRO 31 January 2010, op. cit.
- 184 CSIRO and Bureau of Meteorology, 2012, op. cit.
- 185 CSIRO and Bureau of Meteorology, 2012, op. cit.
- 186 Queensland Floods Commission 2012, *Queensland Floods Commission of Inquiry Final Report*
- 187 ABARES 2011, *Nation looks to ABARES flood analysis*, media release, 1 March 2011
- 188 ABARES 2011, *The impact of recent flood events on commodities*, special report, Canberra
- 189 Wilson, L. and Schliebs, M., 2011, 'Deluge swells wheat prices' *The Age*, Melbourne, 5 January 2011
- 190 ABARES 2011, *The impact of recent flood events on commodities*, op. cit.
- 191 ABARES 2011, *The impact of recent flood events on commodities*, op. cit.
- 192 Wilson, L. and Schliebs, M., 2011, op. cit.
- 193 Blackwell, R., 2011, 'Australia floods hit commodity exports' *The Globe and Mail*, Toronto, 3 January 2011
- 194 Queensland Floods Commission 2012, op. cit.
- 195 Queensland Floods Commission 2012, op. cit. p. 30.
- 196 The Natural Disaster Insurance Review report released on 14 November 2011
- 197 Australian Government Disaster Assist, retrieved 19 October 2012, www.disasterassist.gov.au; Bureau of Transport Economics 2001, *Economic costs of natural disasters in Australia*, report 103
- 198 *ibid.*
- 199 ABC News Online, 8 May 2012, retrieved 19 October 2012, <http://www.abc.net.au/news/2012-05-07/suncorp-wont-offer-new-policies-for-flood-prone-towns/3994612>
- 200 *The Australian*, 2 April 2012, retrieved 19 October 2012, <http://www.theaustralian.com.au/national-affairs/dumped-minister-gives-government-a-blast-over-disaster-spend/story-fn59nix-1226315905936>
- 201 Parliament of Victoria, 2009 *Victorian Bushfires Royal Commission final report* ISBN 978-0-9807408-3-7., Summary, p 5
- 202 <http://www.dpc.vic.gov.au/index.php/featured/reforming-victorias-crisis-and-emergency-management-framework>, accessed 21 October 2012
- 203 CSIRO, 2011. *Bushfire in Australia*. <http://www.csiro.au/resources/BushfireInAustralia.html#1> retrieved 1 August 2011:
- 204 Adams, M. and Attiwill, P. eds 2011. *Burning Issues. Sustainability and Management of Australia's Southern Forests*. CSIRO and Bushfire Cooperative Research Centre
- 205 Adams, M. and Attiwill, P. eds 2011. *Burning Issues. Sustainability and Management of Australia's Southern Forests*. CSIRO and Bushfire Cooperative Research Centre p217
- 206 Keith, D.A., 2002. Population dynamics of an endangered heathland shrub, *Epacris stuartii* (Epacridae): recruitment, establishment and survival. *Austral Ecology*, vol 27, pp 67-76
- 207 Bradstock, R.A., Williams, R.J., and Gill, M.A., 2012, 'Future fire regimes of Australian ecosystems: new perspectives on enduring questions of management' in Bradstock, R.A. Gill, M.A. and Williams R.J., eds *Flammable Australia*, CSIRO Publishing
- 208 Cary, G.J., Bradstock, R.A., Gill, M.A. and Williams R.J., 2012. 'Global change and fire regimes' in Bradstock, R.A. Gill, M.A. and Williams R.J., eds *Flammable Australia*, CSIRO Publishing
- 209 Karoly, D, 2009. *Bushfires and extreme heat in south-east Australia*. Real Climate <http://www.realclimate.org/index.php/archives/2009/02/bushfires-and-climate/#more-654>, retrieved 19 October 2012
- 210 Parliament of Victoria, 2009, *Victorian Bushfires Royal Commission final report* ISBN 978-0-9807408-3-7, Volume I, p 17
- 211 Department of Sustainability and Environment, 2011. *What Causes Bushfire on Public Land in Victoria?*: <http://www.dse.vic.gov.au/fire-and-other-emergencies/fire-management/causes-of-bushfire>, retrieved 01 August 2011

- 212 Stephenson C., 2010, *A literature review on the economic, social and environmental impacts of severe bushfires in South eastern Australia. Fire and Adaptive Management Report No. 87.* Bushfire Cooperative Research Centre
- 213 Leak, M., Passuello, R. and Tyler, B., 2003, 'I've seen fire. I've seen rain. I've seen muddy waters that I thought would never clear again' *Waterworks*, vol 6, pp 38-44
- 214 Cook, P., Holland, D. and Longmore, A., 2008, *Interactions between phytoplankton dynamics, nutrient loads and the biogeochemistry of the Gippsland Lakes*, Water Studies Centre, Monash University, Melbourne.
- 215 GWM Water newsletter, May 2011 http://www.gwmwater.org.au/information/publications/ground-and-surface-water/west-wimmera-gma/doc_download/1285-water-quality-in-the-wimmera-mallee-pipeline, retrieved 19 October 2012
- 216 The Climate Institute, 2011, *A Climate of Suffering: the real cost of living with inaction on climate change.*
- 217 Anastatrio, M., Shehab, N. and Lawry, L. 2006, 'Increased gender-based violence among women internally displaced in Mississippi two years post-Hurricane Katrina' *Disaster Medicine and Public Health Preparedness*, vol 3(1), pp 18-26
- 218 Australian Women's Health Network Newsletter, February 2011. pp 3-4
- 219 Stephenson, C., 2010, *The impacts, losses and benefits sustained from five severe bushfires in south-eastern Australia. Fire and Adaptive Management Report No. 88.* Bushfire Cooperative Research Centre
- 220 Stephenson, C., 2010, *The impacts, losses and benefits sustained from five severe bushfires in south-eastern Australia. Fire and Adaptive Management Report No. 88.* Bushfire Cooperative Research Centre
- 221 Ministerial Taskforce on Bushfire Recovery 2007, *Report from the Ministerial Taskforce on Bushfire Recovery*
- 222 Fogarty, L., and Ackland., A., 2009, 'Understanding and adapting to change: What can our fire climate tell us?' Emergency Management Conference 2009
- 223 CSIRO, 2007 Climate Change Projections for Australia <http://www.climatechangeinaustralia.gov.au/> retrieved 19 October 2012
- 224 CSIRO, 2007 Climate Change Projections for Australia <http://www.climatechangeinaustralia.gov.au/> retrieved 19 October 2012
- 225 CSIRO, 2008 *Bushfire Impacts on Water Yields*. Media Release 22nd Jan 2008..
- 226 Lucas, C., Hennessy, K., Mills, G. and Bathols, J., 2007 *Bushfire in southeast Australia: Recent Trends and Projected Climate Change impacts*, Bushfire Cooperative Research Centre and CSIRO
- 227 Parliament of Victoria, 2009, *Victorian Bushfires Royal Commission final report* ISBN 978-0-9807408-3-7, Volume II, p 222
- 228 Adams, M. and Attiwill, P. eds 2011. *Burning Issues. Sustainability and Management of Australia's Southern Forests*. CSIRO and Bushfire Cooperative Research Centre
- 229 Bushfires Royal Commission Implementation Monitor, 2012, *Final Report*.
- 230 Department of Justice Buyback Scheme guidelines. <http://www.justice.vic.gov.au/buyback> retrieved 19 October 2012
- 231 Tolhurst, K.G., 2009, *Report on Assessing Defendable Space Around Houses 2 in Bushfire-prone Environments*. Submission to the Victorian Bushfires Royal Commission. <http://www.bushfirecrc.com/managed/resource/bushfire-penetration-urban-areas.pdf> <<http://www.bushfirecrc.com/managed/resource/bushfire-penetration-urban-areas.pdf>
- 232 http://www.dpcd.vic.gov.au/_data/assets/pdf_file/0003/86484/Fact-Sheet_Planning-and-building-for-bushfire-protection.pdf
- 233 S. Harris, S., W. Anderson, W. Kilinc, M and Fogarty, L., 2011, *Establishing a link between the power of fire and community loss: The first step towards developing a bushfire severity scale. Fire and Adaptive Management Report No. 89*, Bushfire Cooperative Research Centre
- 234 Stephenson, C., 2010, *A literature review on the economic, social and environmental impacts of severe bushfires in South eastern Australia. Fire and Adaptive Management Report No. 87.* Bushfire Cooperative Research Centre

- 235 Victorian Planning Provisions 52.47 bushfire protection: planning requirements http://planningschemes.dpcd.vic.gov.au/aavpp/52_47.pdf, retrieved 19 October 2012
- 236 UrbAnalyst, 2011, <http://urbananalyst.com/in-the-news/victoria/876-new-bushfire-planning-controls-for-victoria.html>, retrieved 19 October 2012
- 237 Ackland, A, Salkin, O, Blackett, A, Friend, G Fogarty, L., 2010, *Future Fire Management Project. Defining and evaluating alternative fire management options to achieve improved outcomes for community protection, biodiversity and ecosystem services. Otway Pilot Study – Interim Report.* DSE
- 238 Texas A&M Forest Service. College Station, Texas, USA
- 239 Consultancy DTSwildfire: <http://www.dtswildfire.com/Projects>
- 240 Taylor, D. and Wallace, L. 2011. *Bushfire Risk Assessment Model. A quantified method of determining bushfire risk spatially Tasmania.* AFAC & Bushfire CRC Conference 2011, Darling Harbour, Australia.
- 241 O'Neill, S.J. and Handmer, J., 2012, Responding to bushfire risk: the need for transformative adaptation. *Environmental Research Letters*, vol 7, 014018
- 242 CSIRO and BoM, 2012, *State of the Climate*
- 243 PriceWaterHouse Coopers, 2011, *Protecting human health and safety during severe and extreme heat events – a national framework*, November 2011, p3
- 244 Carlson, Ann E., 2008, Heatwaves, Global Warming, and Mitigation, *University of California Los Angeles Journal of Environmental Law and Policy*, The Earth Policy Institute, 2008, p17
- 245 Lobell David B. 1, Sibley, Adam and Ortiz-Monasterio J. Ivan, 2012, Extreme heat effects on wheat senescence in India, *Nature Magazine*, 29 January 2012
- 246 CSIRO, 2007, *Climate Change in Australia – Technical Report 2007*, p48
- 247 Climate Commission, *The Critical Decade: Climate Change and Health*, p13
- 248 Victorian Centre for Climate Change Adaptation Research & LTU, 2011, *Adaptation and Infrastructure think tank report*, 17/06/11, p11
- 249 Howard, L, 2007, *The Climate of London*, London 1818, ref Foxell, S *Mapping London*
- 250 PriceWaterHouse Coopers, 2011, *Protecting human health and safety during severe and extreme heat events – a national framework*, November 2011, p2-3
- 251 PriceWaterHouse Coopers, 2011, *Protecting human health and safety during severe and extreme heat events – a national framework*, November 2011, p2-3
- 252 PriceWaterHouse Cooper, 2011, *Protecting human health and safety during severe and extreme heat events – a national framework*, November 2011, p2-3
- 253 Climate Commission, *The Critical Decade: Climate Change and Health*, p11
- 254 The Climate Institute, 2011, *A climate of suffering*, p259
- 255 The Climate Institute, 2011, *A climate of suffering*, p10
- 256 City of Melbourne, 2009, *Climate Change Adaptation Strategy*, p9
- 257 City of Melbourne, 2009, *Climate Change Adaptation Strategy*, p9
- 258 Department of Human Services Victoria, 2009, *January 2009 Heatwave in Victoria: an Assessment of Health Impacts*, p13
- 259 The Climate Institute, 2011, *A climate of suffering*, p19
- 260 The Age Online, February 3, 2009. *Heat-stressed possums suffer burnt feet* www.theage.com.au/national/heatstressed-possums-suffer-burnt-feet-20090203-7wgp.html
- 261 Low T. Department of Environment and Resource Management, Queensland Government, Brisbane, 2011, *Climate Change and Terrestrial Biodiversity in Queensland*
- 262 ABC News Online, 3 February 2010. Local help needed after endangered bird almost wiped out <http://www.abc.net.au/local/stories/2010/02/03/2809096.htm>
- 263 National Geographic Online, August 5 2011, *Carnaby's black cockatoo in trouble*, www.australiangeographic.com.au/journal/carnabys-black-cockatoo-in-trouble.htm

- 264 Department of Sustainability and Environment, 2009, *Yarra Bend Park Flying-fox Campsite: Review of the scientific research*, p12
- 265 Department of Primary Industries, 2010, *Managing Severe Weather Events*, Final Project Report, 23
- 266 Department of Primary Industries, Victoria, *Dry seasonal conditions in rural Victoria*. Report No. 86. 2009.
- 267 <http://www.beefcentral.com/production/article/1063>
- 268 Dairy Australia, *Cool Cows Online*, www.coolcows.com.au retrieved 18 October 2012
- 269 Dairy Australia, *Cool Cows Online*, www.coolcows.com.au retrieved 18 October 2012
- 270 Dairy Australia, *Cool Cows Online*, www.coolcows.com.au retrieved 18 October 2012
- 271 Lobell David B., Sibley, Adam and Ortiz-Monasterio J. Ivan, 2012, Extreme heat effects on wheat senescence in India, *Nature Magazine*, 29 January 2012
- 272 Extract from a paper currently under review (senior author Graeme Thomson)
- 273 Extreme Heat: Managing Grapevine Response, 1. School of Agriculture and Food Systems, University of Melbourne, 2. Centre for Australian Weather and Climate Research, a partnership between CSIRO and the Bureau of Meteorology, 3. John Whiting Viticulture Consulting.
- 274 Extreme Heat: Managing Grapevine Response, 1. School of Agriculture and Food Systems, University of Melbourne, 2. Centre for Australian Weather and Climate Research, a partnership between CSIRO and the Bureau of Meteorology, 3. John Whiting Viticulture Consulting.
- 275 Department of Health Victoria, 2011, *Heatwave Plan for Victoria*, p1
- 276 Department of Health Victoria, 2011, *Heatwave Plan for Victoria*, p10
- 277 The University of Melbourne, 2011, *Cool Roofs: City of Melbourne*, p4
- 278 The University of Melbourne, 2011, *Cool Roofs: City of Melbourne*, p4
- 279 City of Melbourne Online, 2012, *White roofs make for cooler Melbourne buildings*, accessed online on 18 October 2012 www.melbourne.vic.gov.au/AboutCouncil/MediaReleases/Pages/WhiteroofstomakeforcoolerMelbournebuildings.aspx
- 280 Bosco vertical in Milan, 2012, accessed online 18 October 2012, <http://inhabitat.com/bosco-verticale-in-milan-will-be-the-worlds-first-vertical-forest/>
- 281 Ibid.
- 282 <http://www.water.vic.gov.au/livingvictoria/road-map> accessed 23 October 2012.

