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Australian Greenhouse Office

Climate Change
Risk and Vulnerability

Promoting an efficient adaptation response in Australia

Final Report

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Report to the Australian Greenhouse Office, Department of the Environment and Heritage

By the Allen Consulting Group

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Preface

This report was commissioned by the Australian Greenhouse Office, which is now part of the Department of the Environment and Heritage, as the first step in identifying priorities for the National Climate Change Adaptation Programme.

Whereas climate change has been recognised as an important challenge since at least 1987, it was only with the publication, in 2001, of the Third Assessment Report of the Intergovernmental Panel on Climate Change that the need to plan for adaptation to climate change received broad recognition. This prompted initial work by the Australian Government on adaptation, particularly through the Australian Climate Change Science Programme to gain a better understanding of likely impacts in Australia. Given the novelty of the issue, regional variation and uncertainty in likely impacts of climate change and the breadth of interests potentially affected, work on adaptation remains at an early stage all around the world.

The National Climate Change Adaptation Programme, announced in the May 2004 Budget is an initiative of the Australian Government to commence preparing Australian governments and vulnerable industries and communities for the unavoidable impacts of climate change. Consultations conducted in the course of preparing this report suggest that this national leadership will be generally welcomed.

The report takes a risk management approach to identifying the sectors and regions that might have the highest priority for adaptation planning. It is important to consider how effectively key systems will respond to climate change in coming years, and the development of policies that align the direction and extent of adaptation actions with social objectives and values.

While effective action to reduce greenhouse gas emissions requires a coordinated global response, in which Australia will play its part, adaptation can be effectively advanced at a local scale. Adaptation and mitigation are related, because our success in mitigating greenhouse gas emissions will determine the magnitude (and possibly the nature) of changes to which we must adapt. Greenhouse gas emissions since the industrial revolution make some climate change inevitable, but adaptation is likely to be a progressively imperfect substitute for reducing global greenhouse gas emissions because the more greenhouse gas concentrations in the atmosphere rise, the greater the risk of 'dangerous' anthropogenic interference with the world's climate system that cannot be readily absorbed or prepared for.

This report explores the risks to Australia from the impacts of climate change over the next 30 to 50 years. Within this, an analysis of comparative risks will be important for identifying priorities for adaptation action and planning.

Acknowledgments

The Allen Consulting Group wishes to acknowledge the efforts of a wide range of individuals and agencies in the development of this study.

Roundtable discussions in each State and Territory capital city were a key source of information for this report, and would not have been possible without the generous contribution of time and expertise by the participants (government and non–government) in each of these jurisdictions.

The cooperation and logistical support of a variety of State and Territory government agencies was also a significant contributor to the success of these meetings and other discussions. For providing venues, facilities and coordination for the roundtable discussions, particular thanks go to:

- NSW Greenhouse Office;
- South Australian Office of Sustainability;
- Northern Territory Greenhouse Unit;
- Tasmanian Department of Primary Industries, Water and Environment;
- Victorian Department of Sustainability and Environment;
- Queensland Environment Protection Agency;
- Western Australian Department of Environment;
- Environment ACT; and
- Bureau of Meteorology.

The assistance provided by the Australian Greenhouse Office (AGO) also needs to be acknowledged. AGO sponsored the project, but has also been generous in the provision of additional support in the form of meeting rooms, technical advice, administrative input and documentation.

All these contributions added to the insights and analysis reflected within.

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Executive summary

What climate change is possible for Australia?

There is little doubt that Australia will face some degree of climate change over the next 30 to 50 years irrespective of global or local efforts to reduce greenhouse emissions. The scale of that change, and the way it will be manifested in different regions is less certain, but climate models can illustrate possible effects. Applying a range of these models to Australia for the range of global emissions scenarios generated by the Intergovernmental Panel on Climate Change (IPCC) for its Third Assessment Report, CSIRO has identified a number of possible outcomes:

- an increase in annual national average temperatures of between 0.4° and 2.0°C by 2030 and of between 1.0° and 6.0°C by 2070 — with significantly larger changes in some regions by each date;
- more heatwaves and fewer frosts;
- possibly more frequent El Nino Southern Oscillation (ENSO) events — resulting in a more pronounced cycle of prolonged drought and heavy rains;
- possible reductions in average rainfall and run–off in Southern and much of Eastern Australia with rainfall increases across much of the Tropical North — as much as a further 20 per cent reduction in rainfall in Southwest Australia, and up to a 20 per cent reduction in run–off in the Murray Darling Basin by 2030;
- more severe wind speeds in cyclones, associated with storm surges being progressively amplified by rising sea levels;
- an increase in severe weather events — including storms and high bushfire propensity days; and
- a change in ocean currents, possibly affecting our coastal waters, towards the end of this period.

Of these possible results, the most likely are for temperature change (including heatwaves and reductions in frosts), sea level rises and increases in cyclonic wind intensity. This does not mean that the results of the models for other possible dimensions of change — rainfall, run–off, non–cyclonic severe weather events — should be disregarded, as they still provide a useful basis on which to test the sensitivity of different systems — natural and human — to the possible scale of change. They should not, however, be regarded as forecasts but rather as indications of possible directions and scale of change. The wisest approach is to use these projections as 'thought experiments' to assess the additional risk — the potential exposure to hazards to life, biodiversity, or economic interests — that changes on this scale could pose.

The period through to 2030, and to a lesser extent 2050, is the one that is most relevant today for decisions about adaptation strategies. This is because most decisions that could be affected by climate risks involve assets and business systems whose economic life falls within or near this time horizon.

Why have an adaptation strategy?

Over the past decade or more the national and international focus has predominantly been on strategies to reduce greenhouse emissions. There has been, in many countries and in the international negotiations on climate change, an unwillingness to devote serious attention to adaptation strategies.

Some level of climate change is inevitable irrespective of emission reduction strategies. This inevitability is reflected in the conclusion of the IPCC in their 2001 Assessment Report that adaptation is now a necessary strategy to complement emission mitigation efforts. The Australian Government's decision to fund the development of an adaptation strategy is therefore an important step forward. Policymakers and investors daily make decisions that have far–reaching and sometimes irreversible effects on the environment, economy and society. These decisions will sometimes be sensitive to assumptions about future climate conditions. Frequently, expectations of future climate are implicitly, or explicitly, based on a continuation of *past* patterns. This could be costly. Some sectors, like insurance and re–insurance, are already including climate risk in their decision making. Governments will need to consider the issues around the distribution of losses in the community arising from the possibility of either a withdrawal of insurance from covering some risks, a huge increase in costs, or the failure of one or more major companies. An adaptation strategy will aim to increase the resilience of human and natural systems to possible changes in climate conditions where this is likely to be feasible and cost effective, and takes account of the social dimensions of distributing losses. It is a framework for managing future climate risk. It offers the potential of reducing future economic, social, and environmental costs as well as protecting life.

An adaptation strategy, to be effective, must result in climate risk being considered as a normal part of decision-making, allowing governments, businesses and individuals to reflect their risk preferences just as they would for other risk assessments. In this sense, adaptation strategies will fail if they continue in the long run to be seen in a 'silo' separate from other dimensions of strategic planning and risk management. To reach this point, however, is going to require a period of awareness raising, development of the science, and development of techniques for applying it in practical situations. This is a common path in developing public policy in 'new' fields. The first step is to identify priorities.

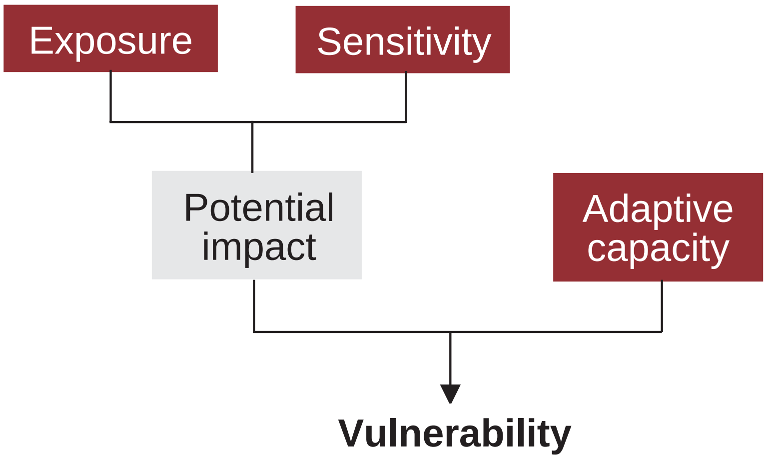
Identifying priorities

Many of our human and natural systems are strongly influenced by climate. All of our natural ecosystems have evolved in variable, but generally slowly changing climate patterns. Industries and communities are also affected by climate factors. Climate can influence productivity and reliability of supply. The community also expects that our cities and infrastructure will cope with severe weather events efficiently and safely. Improved technical knowledge and modern communications are tending to increase understanding of the relationship between climate exposure and national welfare.

Prioritising adaptation action requires the identification of vulnerable systems — human and natural — the costs if these fail, the scope to reduce this risk, and the ability to capture any potential benefits. Vulnerability is a function of exposure to climate factors, sensitivity to change and capacity to adapt to that change. Systems that are highly exposed, sensitive and less able to adapt are vulnerable. This is illustrated in Figure ES.1 below. Adaptation strategies therefore involve the identification of sectors/systems/regions vulnerable to change and an examination of the scope to increase the coping capacity of those systems — their resilience — which in turn will decrease that vulnerability. Prioritisation will also depend on identifying vulnerable systems or regions whose failure or reduction is likely to carry the most significant consequences. Our framework for assessing comparative risk thus incorporates system vulnerability, the consequences of system failure or reduction, and the scope to improve likely outcomes through planned adaptation.

Figure ES.1

VULNERABILITY AND ITS COMPONENTS



Source: Adapted from D. Schroter and the ATEAM consortium 2004, *Global change vulnerability — assessing the European human–environment system*, Potsdam Institute for Climate Impact Research.

There is some debate about the 'realism' of the IPCC scenarios for temperature change through to 2100 on which some of the CSIRO climate projections rest. In recent time this has focused on the projections of emissions over the century. Some economists have suggested that the IPCC methodology overestimates real income growth in developing countries, implying emissions growth rates that are also too high. There is considerable debate amongst economists about whether this is the case. This is a worthy issue for debate, but it is not materially relevant for the 30 to 50 year time frame which is the focus of this study.

Much of the climate change likely to be observed over the next few decades will be driven by the action of greenhouse gases already accumulated in the atmosphere. The period through to 2030, and to a lesser extent 2050, is the one that is most relevant for early decisions about adaptation strategies. Replacement and refurbishment decisions for most of the assets within the economy will be made within this time frame, together with design decisions on longer lived assets — some of which may well face significantly increased climate stresses in the future. Planning now for climate change, and its potential risks, can help ensure Australian industries and communities are well placed to deal with climate conditions in the future.

Better information on regional climate change and potential outcomes is a key requirement. Regional climate is determined largely by the nature of the large–scale meteorological features such as the ENSO pattern and the Southern Annular Mode, and understanding changes in these systems is a major part of understanding climate change at a regional level.

Any climate change signal will be overlaid on an Australian climate that is already highly variable and where there is more work to do in identifying and attributing such changes as have already happened. However, recent climate events, such as the drought conditions affecting Australia, heatwaves, bushfires, storms and the hurricane events of Florida and the Caribbean can help illustrate the nature of key stresses that might be placed on natural and human systems by a climate driven by progressively warmer temperatures.

Priority vulnerable systems and regions

On the basis of the application of this framework to possible priority sectors and regions identified through a review of the literature and meetings with key stakeholders in all capital cities, The Allen Consulting Group has identified the following priority vulnerable systems and associated regions. These reflect considerations of climate vulnerability, the significance of the systems at risk and the likely need for government intervention to encourage a timely and efficient adaptation response.

Ecosystems and biodiversity

- alpine regions;
- reef systems (such as Ningaloo and the Great Barrier Reef);
- tropical rainforest areas;
- heathland systems in southwest Western Australia;
- coastal mangrove and wetland systems (such as Kakadu); and
- rangelands.

Within this group, particular priority should be given to World Heritage listed systems. Such systems and areas have properties of uniqueness and ecological importance that have been confirmed against an international yardstick. However, there is a need to face the prospect that, in some cases, the may be little that can be done. Climate change might overwhelm some fragile species and remnant habitats (such as those in alpine regions) that literally have nowhere else to go, or for which effective options for supplementing their natural adaptive and coping capacities — through actions such as relocation, developing migratory corridors or relieving other environmental pressures — are extremely limited.

Biological systems are likely to come under significant pressure from climate change, which is likely to proceed at a rate that will exceed their natural adaptive capacities. In some cases there may be scope to assist the adaptation of vulnerable systems and species, and work should proceed on identifying the most effective options. The threat from climate change should be explicitly factored into planning and actions undertaken under a range of existing initiatives such as the National Heritage Trust, world heritage management and the National Reserve System, and the preparation of recovery and threat abatement plans under the Environment Protection and Biodiversity Conservation Act 1999. The findings of this report should also give further impetus to the National Action Plan for Biodiversity and Climate Change. However, it is likely policymakers will need to adopt a triage approach — aimed at investing effort where the benefits to biodiversity and important ecosystems are likely to be greatest.

Agriculture

Agricultural systems have shown considerable capacity to adapt to the climate — changes in land management practices, crop and cultivar choice and selection of animal species and technologies to increase efficiency of water use have all been used to change the geographic and climate spread of our agricultural activities. All of these activities could and will be deployed by farmers to respond to climate change, although as the degree of climate change increases the limits of this adaptive capacity may be tested. There may be some gains in some regions emerging from low levels of climate change as a result of longer growing seasons, fewer frosts, higher rainfall (northern Australia) and CO_2 fertilisation.

The agri–business units and regions most at risk will be:

- those already stressed — economically or biophysically, as a result of land degradation, salination and loss of biodiversity;
- those at the edge of their climate tolerance; and
- those where large and long lived investments are being made — such as in dedicated irrigation systems, slow growing cultivars and processing facilities.

Adaptation strategies to increase resilience of the agricultural sector could include research on cultivars that are capable of handling temperature stress and drought, selection and development of livestock for temperature and pest resistance, and better information on climate risk parameters for those making long term investments so that they can be weighed along with other risks. Micro–economic policies for the sector — particularly under the National Water Initiative and the National Action Plan for Salinity and Water Quality — could be examined to ensure that they expose rather than suppress opportunities to adapt. There may also be a role for Australian Government programs such as 'Agriculture – Advancing Australia', which is designed to help primary production become more competitive, sustainable and profitable.

Water supply

The availability of water is essential for many industries and other natural resources. Every major mainland city faces water stress already. In many cases climate change will increase these pressures through increased temperature and possibly lower rainfall combined with more frequent ENSO events. Dams could be susceptible to extreme rainfall events if these exceed historical design standards. Dam overtopping and failure can have catastrophic short and medium term effects in terms of human and economic losses.

Adaptation options for urban water and dams could include systematic inclusion of climate risk — on both the supply and demand side — in all our major urban catchments. There is much work already progressing in this area. Multi–jurisdiction partnerships through the CRCs on catchment hydrology, freshwater ecology, and water reuse, and with the Bureau of Meteorology and CSIRO could support a more efficient deployment of collaborative research capacity and the development of robust, substantially transferable catchment models and decision support tools. Similarly, collaborative work on assessment of non–conventional water supply sources — desalination, water recycling — and on demand management could be a high priority under the National Water Initiative. The National Committee on Large Dams could also be approached to ensure that future climate risks are adequately reflected in current standards.

Settlements and emergency services

Exposure of our cities to climate patterns is high — but the sensitivity to change depends very much on the way it impacts on extreme events. Urban areas and the built environment are machines to manage and control climate. Our cities and infrastructure are built to accepted risk limits based on the expected return frequency of severe winds, heavy precipitation events, storm surges and so on. Below these thresholds, severe weather events are usually handled with relatively light damage to property and human health and life. Above the thresholds, however, damage, injury and death can accelerate in a non–linear way.

If climate change increases the energy of tropical cyclones and severe non–tropical depressions then the return frequency of severe storms (like cyclone Tracy) could reduce significantly with an associated increase in exposure. Linked with increasing sea level and hence more dangerous and extensive storm surges, this could put some of our significant population and tourist centres like Cairns, Broome, Darwin and Townsville, as well as remote communities, at considerably increased risk.

In many temperate urban and rural centres, any increase in severe weather events linked with climate change — bushfires, heavy and sustained rainfall, high winds and in particular cyclones, sustained heatwaves — could cause significant damage. This is particularly so in inner areas of older cities that have progressively increased population density and hardened surfaces above stormwater infrastructure put in place fifty or more years ago. Demographic changes could exacerbate these effects as they impact both on the volunteer base for emergency services and increase the population at risk.

Adaptation options for urban systems and emergency services would include ensuring that the current study of emergency management priorities and responses being carried out at the Council of Australian Governments' (COAG's) direction, systematically includes the additional risks posed by climate change. Action in this area should build on existing programs and responsibilities. Deliberations under the Australian Government's Disaster Mitigation Australia Package should also be informed by climate change risks. Consideration of the greater risk of heat stress and the ageing of the population might be relevant to thinking on future emergency services needs. Local Government will have an important role to play in designing and delivering adaptation options for urban systems.

There may also be merit in a specific multi–jurisdictional/multi–sector analysis of tropical centres — including remote settlements — prioritised by risk, to examine their sensitivity to increased return frequency of high intensity cyclones and progressively increased storm surges due to sea level rises. The aim would be to assess and rank possible options ranging from warning systems to emergency response capacity, through hardening key elements of infrastructure used in recovery, to changes in infrastructure, planning and building rules and possibly even the upgrading of key buildings to ensure that they meet tougher standards, or the withdrawal of populations from particularly exposed areas.

At a lower priority there could also be merit in each of our major metropolitan areas conducting multi–disciplinary studies — reflecting a partnership of Commonwealth, State and local governments — examining the inter–linkages between climate change and thresholds of sensitivity in human (urban, rural, infrastructure, economic, health and social) and natural systems. Input from key decision makers from all sectors of the community, including Indigenous communities and vulnerable groups such as the aged, could be obtained.

The Australian Government has a range of programs to strengthen regional communities, and it may be advantageous for some of these to take the likely impacts of climate change into account.

Energy

Demand for energy is temperature sensitive (increasingly so with the penetration of domestic air–conditioning) with peaks both changing from winter to summer and steepening. Electricity supply is sensitive both to extreme weather related events and in some cases temperature itself as it degrades transmission capacity. Supply sensitivity also extends to disruption to platform operations (as has happened recently in the Gulf of Mexico with direct consequences for global energy prices), transmission and distribution (including impacts of land slip and storm on very long gas pipelines and storm and bushfire on electricity distribution). Most of Australia's energy infrastructure — generation and transmission/distribution — is now at, or approaching, the point where there is little redundancy at peak periods and reduced capacity to sustain cumulative impacts. Our economic, social and household systems are now so interdependent while being simultaneously dependent on a reliable, high quality energy supply that a failure in that supply brings much higher economic and social costs than at any time in the past. Much of the sector is subject to price regulation in one form or another, and it is not clear that regulators are as yet sensitive to the pressures that might be placed on infrastructure by climate change, and hence the possible need to allow some level of redundant capacity.

Climate change risks and implications need to be factored into Australia's energy planning. Adaptation options for energy could include a program of studies of our energy systems' sensitivity to climate events — in particular sustained heatwaves and severe weather events — as an additional risk factor to those already facing the system. System stability in the face of cumulative events, including climate events, could be examined. These studies could be regionally based. They could also examine the stability of the Eastern States grid, reflecting

- *the interaction between energy sources and energy infrastructure, including between generation, transmission and distribution; and*
- *the increasing dependence of our economic and social systems on uninterrupted energy supply.*

Independent regulators could usefully be drawn into these studies.

Other areas for particular attention could include demand management and energy conservation strategies aimed particularly at temperature driven peak demand, interval pricing, minimum energy standards for air–conditioning, passive thermal design requirements in domestic accommodation (already increasingly required but in an uncoordinated way across Australia) and options for improving the performance of the existing stock of dwellings.

In addition, the recent impact of high intensity hurricanes on operations and gas and oil production infrastructure in the Gulf of Mexico suggests that a review of the adequacy of current regulatory requirements and emergency management protocols for Australia's off shore energy infrastructure against the background of possibly reduced return frequencies for severe cyclones could be merited.

Regions

Climate vulnerability also has important regional dimensions. Climate variability is inherently a phenomenon that will play out at a geographic level and put greater pressure on some regions than others. Similarly, some regions will be more vulnerable to these pressures. They may already be under significant stress, embody several climate sensitive industries or systems and have recognised national significance. Vulnerable areas (and associated communities) include:

- low lying coastal population and resort centres;
- tropical and sub–tropical population centres;
- alpine regions;
- centres with a high dependence on agricultural and/ or eco–tourism activities;
- remote Indigenous communities (particularly in the far north of Australia); and
- areas of southern Australia facing acute water shortages and supply constraints.

However, within this grouping a handful of highly vulnerable regions can be identified that should be given priority for further adaptation planning and response. These are:

- Cairns and the Great Barrier Reef;
- Murray Darling Basin; and
- south west Western Australia.

These regions exhibit a potent combination of exposure to climate change, sensitivity and need for facilitative adaptive action. An ongoing dialogue between industry, governments and the scientific community is required, aimed at addressing the threat that climate change poses for these areas.

Regional adaptation planning requires coordination across all levels of government and the involvement of industry, scientists and community leaders. It must be informed by a thorough and ongoing analysis of the climate threat and viable adaptation options, recognising the inter–linkages and dependencies of the many human and natural systems that operate at a regional level. Planners need to anticipate future climate pressures and build the capacity of systems to cope with these pressures (and/or relieve other stresses) if the adverse implications of climate change are to be minimised.

Pulling it all together

Climate change can influence, and react with, a range of macro variables. Within Australia it can be a driver of internal migration and production patterns, and interact with demographic and behavioural trends with implications for future health care and community services needs. Australia will also be influenced by overseas climate impacts and their effect on commodity prices, trade volumes and socio–economic factors, including pressures for disaster relief and migration.

The common thread in stakeholder discussions across all capital cities was a desire to build on existing effort and for strong national leadership on climate change adaptation. This was expressed by senior representatives of industry, non–government organizations, the science community as well as by State and Local Government. National leadership was seen as important in four ways:

- to confirm at the most senior level that careful thought should be given by governments at all levels, the private sector and communities to managing climate risk;
- to improve understanding of the current status of climate science, and provide a framework within which the necessarily collaborative and multi–disciplinary effort required to advance it can be structured;
- to coordinate reviews and development of strategies for identifying and managing risk in vulnerable sectors and regions with the aim of gaining economies, sharing learning and developing synergies; and
- to provide decision support tools that could assist local government, the private sector and households to integrate climate risks into key decisions.

Australian Government–State partnership

Much of the implementation of any adaptation strategy would inevitably be the responsibility of the state, territory and local governments reflecting their key roles in public infrastructure, safety, health and land use planning and control. Key adaptation issues span virtually all portfolios and governments. Building on existing effort to integrate planning and management for climate change will be important.

Climate science for adaptation

Climate science to underpin adaptation has three principal streams:

- progressive development of climate models and associated infrastructure to provide regional—scale information, based on progressively enhanced global monitoring systems;
- more sophisticated modelling of global emissions scenarios allowing for feedback loops with climate systems and probabilistic assessments as an aid to adaptation planning; and
- multi–disciplinary approaches to linking climate models to spatial models of terrestrial systems (hydrology, biodiversity, crop productivity, disease vector spread) and testing sensitivity thresholds of vulnerable human and natural systems.

The first of these streams sits within a global effort. It is characterised by large-scale systems of great complexity. The second stream also has global dimensions through the IPCC. Integrated effort across CSIRO, the Bureau of Meteorology, together with the universities and decision makers will assist in creating well-targeted and efficient use of the research dollar.

The third stream — adaptation science — is complex and has been characterised over the last 15 years by what one observer has called ‘cottage industries’. It is a stream that is at its core multi–disciplinary and fully consistent with the National Research Priorities.

Coordinated cross sectoral reviews of vulnerable regions and centres

Integrated assessments of regions will be needed to better understand the vulnerabilities and the adaptation options. Vulnerability assessment does not need to await developments in climate science. System sensitivity to climate change and adaptive capacities and planned response options are equally important factors in assessing vulnerability. Early consideration of these elements will provide the maximum opportunity for a timely and effective response to climate change.

Private incentives and markets

Most climate risk management decisions will be made by decentralised decision makers in the private sector, local government and by households. The development of Australian–based decision support framework and guides will be necessary to support decision makers. There is a role for governments to work in partnership with industry and communities to increase the understanding of climate change impacts and actions to improve adaptive capacity.

Promoting incentive structures that encourage efficient resource allocation, market development and consistency of private decision making and community values is particularly important in a ‘change’ environment.

Chapter 1

Introduction

Human beings are highly adaptable. We have a gift for innovation that enables us to survive and even flourish in hostile environments that would challenge other creatures. Mankind has learned to adapt to the rigours of life at high altitudes, in freezing conditions, in the deserts, in earthquake and flood prone areas and even in space. Mankind has a great ability to survive, and can also aid the survival of other species. Yet despite all these adaptive skills some environmental conditions are clearly more preferable — and conducive — to an enriching and sustainable quality of life than others.

Huge investments have been made over the last two hundred years on the assumption that climate is relatively stable (or at least displays a fairly predictable degree of variability). The design of our homes and where we build them, the capacity of our dams, the crops we grow on particular plots of land, the reserves we have set aside to preserve biodiversity and many other aspects of modern life in Australia are based on the assumption that the climate over the next twenty years will be much the same as the climate for the last twenty years. However, there is sound evidence that the climate and its variability are changing.

Although governments around the world have embarked on programs designed to cut greenhouse gas emissions that drive climate change, momentum for a change in climate conditions is already established. There is growing evidence of shifts in climate patterns — with flow–on effects for established environmental, economic and social structures and systems. As greenhouse gas concentrations in the atmosphere rise further, more changes are likely, and the risk grows that significant thresholds and balance points in the Earth's systems will be exceeded.

Atmospheric concentrations of carbon dioxide are already at a level that is unprecedented in human history, and perhaps not experienced by any species in the past 20 million years.

This is a reminder of the goal of the United Nations Framework Convention on Climate Change: to reduce greenhouse gas emissions to a level that would prevent dangerous interference with the global climate system. Science is not yet able to tell us where all the critical thresholds lie and judgements about when we will cross over into the realm of 'dangerous' climate effects must necessarily involve social, economic and political as well as scientific considerations. However, there is now broad agreement within the expert scientific community that climate change is occurring, and as greenhouse concentrations increase so does the risk of setting in motion an adverse and irreversible climatic response. There is little doubt that human activities are adding to natural changes and variations in the climate system.

While efforts to reduce global greenhouse gas emissions remain a key focus for policymakers, there is a need for governments and private decision makers to assess their options and capabilities for dealing with the potential effects of climate change.

In some ways changes to the global climate system will be gradual. However, given the complexity and highly non–linear nature of the climate system, some changes could happen quickly and put intense pressure on systems. Small shifts in average climatic conditions can be associated with significant changes in the frequency and intensity of extreme events — affecting return periods for climate phenomena such as coastal storm surges, extreme rainfall and high wind conditions. Changes in all these elements — which may or may not be related to climate change — have been observed over the last century. Science tells us that such changes are set to continue and some systems will be more able to cope with these changes than others.

It will be important to understand these risks, and identify priorities for government in minimising the disruptions and losses that can be driven through potential future changes in established climate patterns.

This report has a significant focus on identifying sectors and regions where adaptation is a high priority. However, this should not lead us to lose sight of the fact that climate change impacts could have macroeconomic effects extending beyond particular sectors or regions. Since these effects are currently difficult to quantify and require further study and analysis, the discussion here is limited to identifying the general nature of the effects.

Climate change will impose direct costs, and possibly confer a smaller number of direct benefits, on the economy. Costs are likely to arise from a number of the biophysical impacts described later in this report. Examples include the potential for higher insurance premiums due to more frequent extreme weather events, possible lost production due to more severe and frequent droughts, and the potential for reduced runoff in much of southern Australia to affect the cost of water. Estimating these costs is very difficult given our current state of knowledge.

Indirect costs can also be expected, and these are even more difficult to estimate. Indirect costs include those associated with reduced environmental amenity and poorer health outcomes.

Macroeconomic effects are not limited to the direct and indirect costs of climate change. A full analysis would also take account of how changes in the relative return on investment from different industries affects the pattern of economic activity in Australia and globally.

The possible trade effects of climate change are difficult to unravel, and a brief discussion of some aspects appears later in this report. The basic issue is that, because changes in climate and vulnerability to these changes is not expected to be uniform around the world, climate change could have varying effects on the comparative advantage of different industries in different countries. For example, warmer conditions in some parts of the northern hemisphere where water is not a limiting factor for crop production may be an advantage to grain producers, while dryer conditions in more arid environments, such as Australia and Africa, could be a disadvantage. Similarly, degradation of coral reefs as a result of global warming could affect the attractiveness of some destinations to international tourists while leaving the attractiveness of other sites relatively untouched.

Finally, it is important to note that climate change will be only one of many factors affecting the Australian economy in the future and that there is considerable uncertainty attached to most or all of these likely influences.

1.1 Identifying priorities within a risk and vulnerability framework

The Allen Consulting Group was commissioned by the Australian Greenhouse Office (AGO) to provide a high–level strategic risk and vulnerability assessment of climate change impacts in Australia, and to identify and prioritise risk management approaches for the Australian Government, industry and regional communities (terms of reference are reproduced at Appendix A). This work is linked to the establishment of an Australian Government initiative, the National Climate Change Adaptation Programme, announced in the 2004-05 Budget.

In advancing analysis of this nature it is important to draw on the full range of stakeholder perspectives, surveying attitudes to work and processes that have gone before and thoughts on priorities for the future. Issues vary according to the activities, location and attitudes of stakeholders. The process of planning for climate change, and indeed acceptance of the need to commence planning, can also be more firmly established in some jurisdictions and constituencies than others. Differences in circumstances and attitude can have a profound effect on the nature of Australia's national adaptation response. The existing literature on climate change and potential Australian impacts, extensive as it is, needs to be supplemented with stakeholders' 'on the ground' assessments of issues, opportunities and imperatives to form a more complete picture of priorities and risks.

For the purposes of this study, we have adopted an outlook of 30 to 50 years. This looks ahead to the types of changes and challenges that current Australian policymakers and communities might face within their current lifetimes, and reflects a planning horizon that, although long term, still lies within the productive life of key capital and infrastructure investments within our economy, and the scope of intergenerational planning.

Determinants of vulnerability

Climate vulnerability refers to a system's potential for suffering damage or ill effects as a result of climate change.

Of course, there will be instances where climate change can alleviate existing climate pressures on some systems. However, the scientific evidence is such that only the most naively optimistic observer could entertain the prospect of climate change representing an overall benefit.

There is an increasing likelihood that climate change will inflict the need for adjustments of established eco–systems on a scale and timeframe that is unprecedented in human history. Further, such changes are entirely unplanned and uncontrollable with an ever increasing risk that, as the concentration of greenhouse gases in the atmosphere grows, so too does the prospect of irretrievable damage to important planetary systems. While it is important not to lose sight of the fact that climate change will generate opportunities as well as threats, there is a burgeoning body of analysis and expert scientific opinion to suggest that the potential and likely costs far outweigh the benefits.

The Intergovernmental Panel on Climate Change (IPCC) has focused on vulnerability as:[1]

[1] IPCC 2001, *Third Assessment Report*, p 388. This definition accords with the Pew Centre, which has defined vulnerability as 'a measure of a system's susceptibility to climate change, which is a function of the system's exposure, sensitivity and adaptive capacity,' (see Pew Centre 2004, *Coping with Climate Change: The Role of Adaptation in the United States*, p 3.) and the US Department of Energy, which has defined vulnerability as

> The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity.

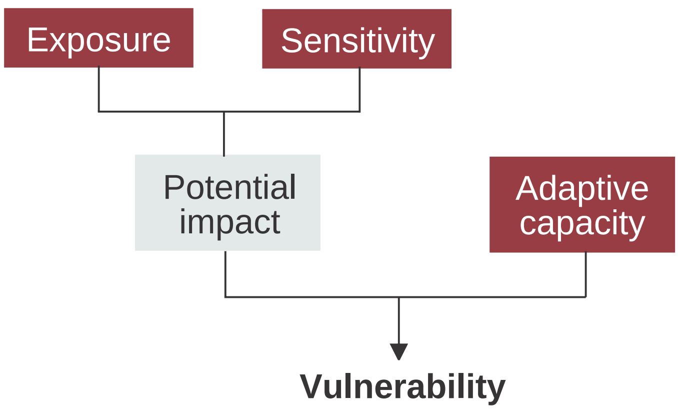
According to this approach, and as illustrated in Figure 1.1, the vulnerability of a system is a function of 3 elements:

- exposure (to climate change effects);
- sensitivity; and
- adaptive capacity.

This approach to vulnerability assessment is important because it highlights the key elements that combine to amplify (or alleviate) the costs and risks that climate change can impose on a system. Understanding these elements can help us identify the threat from climate change, and action in each of these areas can help us reduce or deal with that threat.

Figure 1.1

VULNERABILITY AND ITS COMPONENTS



Source: Adapted from D. Schroter and the ATEAM consortium 2004, *Global change vulnerability — assessing the European human–environment system*, Potsdam Institute for Climate Impact Research.

Exposure

Exposure relates to the influences or stimuli that impact on a system. In a climate change context it captures the important weather events and patterns that affect the system, but can also represent broader influences such as changes in related systems brought about by climate effects. Exposure represents the background climate conditions against which a system operates, and any changes in those conditions.

'the sensitivity of a system or process to climate change (the degree to which outputs or attributes change in response to changes in climate inputs) and the adaptability of that system (the extent to which changes are possible to take advantage of the new conditions). It departs from hazard definitions, which have historically defined vulnerability as the probability of a hazard and the magnitude of the damage — ignoring the potential for adaptation options.

Sensitivity

Sensitivity reflects the responsiveness of a system to climatic influences, and the degree to which changes in climate might affect it *in its current form*. Sensitive systems are highly responsive to climate and can be significantly affected by small climate changes. Understanding a system's sensitivity also requires an understanding of the thresholds at which it begins to exhibit changes in response to climatic influences, whether these system adjustments are likely to be 'step changes' or gradual, and the degree to which these changes are reversible.

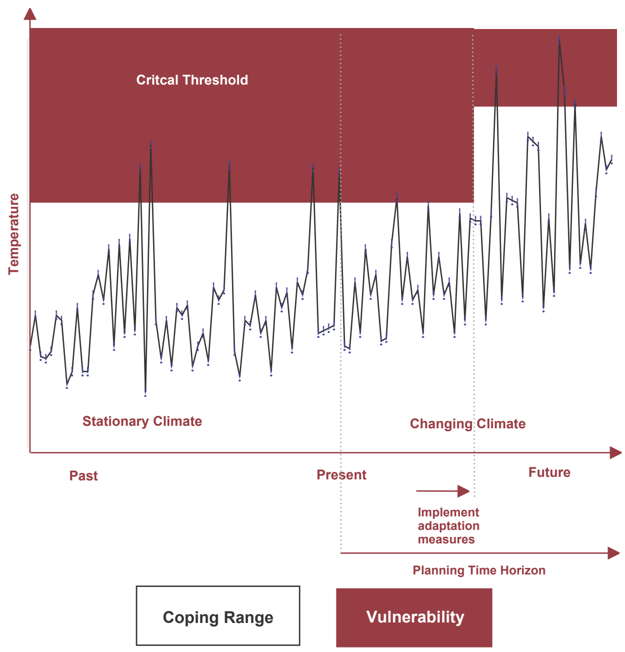
Adaptive capacity

Adaptation reflects the ability of a system to change in a way that makes it better equipped to deal with external influences. Adaptation can be either planned or autonomous. A *planned* adaptation is a change in anticipation of a variation in climate. It is an inherently strategic and conscious effort to increase the capacity of a system to cope with (or avoid) the consequences of climate change.

This approach is represented in Figure 1.2 below. In this stylised situation, the path of climate change increasingly tests the 'coping capacity' of an existing system. Advance planning can help increase the coping capacity of the system. Systems also have a capacity to improve their ability to cope over time as a reaction to climate pressures. This is commonly known as *autonomous* adaptation.

Figure 1.2

PLANNED ADAPTATION: REDUCING VULNERABILITY TO CLIMATE CHANGES



Source: Adapted from UKCIP (R.I. Willows and R.K. Connell (eds)) 2003, *Climate Adaptation: Risk, Uncertainty and Decision making — UKCIP Technical Report*, UKCIP, Oxford.

Importantly, systems whose autonomous adaptive capacities are unlikely to be capable of dealing with climate pressures may need to supplement these with planned approaches in order to minimise adverse effects. Planning allows adaptive responses to precede critical climate pressures, and proceed in a coordinated way.

There are two additional aspects to assessing the vulnerability of the system to climate change. These are adverse implications, especially from a social and economic perspective, and the potential to benefit from adaptation intervention.

Adverse implications

Adverse implications are an estimate of the loss that could occur due to climate change impacts. There are currently few studies that attempt to put a value on the costs to the nation or local community of important systems faltering or failing under the influence of climate change, or associated extreme events. Because industries and systems are interlinked an economy–wide (or indeed, integrated climate–population–economy) model would be the appropriate tool to undertake this analysis. However, data and other information constraints would be a significant impediment to obtaining accurate and reliable comparative analysis between sectors and regions.

At this stage, we must make judgments about the inherent values of systems from both an economic and social perspective. Contributions to the economy are important, and changes in this can be judged against metrics such as income, employment and contributions to the nation’s capital stock. Contributions to regional economies can also be important, together with concerns about community health and wellbeing. Ideally, we should also examine the costs associated with changes in the incremental performance of systems under alternative levels and timeframes of climate change.

Potential to benefit

The potential to benefit is an estimate of what potential the sector or region has to introduce adaptation options, and therefore benefit. Assistance will be needed to foster comprehensive analyses of alternative adaptation strategies for regions and/or sectors. At one end of the scale, it is widely recognised that the effectiveness of human effort in assisting fragile species or ecosystems cope with climate change may be severely constrained. However, some adaptation options have been identified for agriculture which have a high potential to benefit the sector.

Although ‘potential to benefit’ is an important consideration in developing adaptation research and response priorities, it is too early to rule any system out of consideration on the basis that it would be unresponsive to efforts to supplement its existing capacities for resilience and adaptation. Such a judgment would need to be formed on the basis of future experimentation, observation and effort. However, in considering criteria that are relevant to priorities for future action, it can be important to extend thinking on the likely *responsiveness* of systems to action to the *need* for action.

Identifying priorities

In a resource–constrained world, decision makers must determine how to allocate time and effort in a way that is most likely to minimise the adverse impacts of climate change. This requires that an analysis of system vulnerabilities be overlayed with a thorough consideration of costs and benefits. Two dimensions are particularly relevant. These are:

- the adverse consequences that would flow from the failure or reduced performance of a climate affected system; and
- the pay–off to efforts aimed at reducing these adverse effects (i.e. the cost effectiveness of the response).

This decision framework lends itself to choices about resource allocation, and identifying priorities for action that focus on the threats posing the greatest future cost, and that will be most responsive to anticipatory action. In some cases modest advance action could avert significant future costs. In others, significant effort might deliver little benefit — and merely divert resources away from activities offering a higher pay–off in terms of their ability to strengthen or protect other vulnerable systems.[2]

This reasoning points to an analytical framework as depicted in Table 1.1. Activities can be assessed to determine their vulnerability, and compared in terms of the costs they would impose if they were disrupted, and their responsiveness to actions intended to reduce or circumvent that outcome. Although decisions on all elements would require a degree of subjectivity, such a framework would lend itself to a reasonably transparent and semi–empirical comparative analysis of options and outcomes. The illustrative assessment in Table 1.1 shows the use of qualitative 'high' and 'low' rankings for activities against vulnerability and cost effectiveness criteria.

Table 1.1.

AN ILLUSTRATIVE VULNERABILITY ASSESSMENT MATRIX

	Sector			
Criteria	Sector 1	Sector 2	Sector 3	Sector 4
Exposure	high	low	low	high
Sensitivity	high	low	high	high
Adaptive capacity	low	high	low	low
Adverse implications	high	low	high	low
Potential to benefit	high	low	high	low
Overall priority	**HIGH**	**LOW**	**HIGH**	**LOW**

Source: The Allen Consulting Group

[2] The same framework applies to decisions about capturing or capitalising on the potential benefits of climate change. A balanced and effective adaptation strategy should focus on cost effective opportunities to minimise the costs of climate change and maximise any benefits, as part of efforts to minimise net costs at a national level.

Acknowledging the uncertainties

Uncertainty is a key obstacle to climate change planning. Although climate change modelling is generating an increasingly robust depiction of the Earth's climate systems, and how these are likely to respond to further accumulation of greenhouse gas emissions in the atmosphere, projections of future climate changes still occupy a relatively broad range of possible climate outcomes. Similarly, the climate problems, potentials and panaceas that might apply to systems are far from clear. Some inroads have been have made in this area, but it will be a long path to achieving a complete and detailed understanding of the climate threat that faces the myriad of human and natural systems that we currently rely on, how well these systems can deal with this threat, and how we might best supplement these efforts.

Key difficulties include:

- uncertainty regarding future climate outcomes globally, and at a detailed regional level;
- difficulties in establishing and valuing system–specific responses to climate change;
- incomplete information on the array of activities that operate within broad industry groupings and across regions (e.g. graziers can face different issues to grain growers although they both populate the agriculture sector, and the threats, responses and options of a wheat farmer in WA can differ significantly from those of a wheat farmer in NSW);
- limited current knowledge of the menu and likely cost effectiveness of possible support and supplementation options that might be applied to climate–vulnerable systems; and
- limited knowledge of the detailed interaction and inter–dependencies of climate affected systems.

These difficulties alone highlight the need for greater research and information gathering as an input to the national adaptation policy agenda. Through analysis and consultation undertaken in the context of this report it has also been feasible to identify salient information needs and a set of activities, tools and processes that can make a substantial contribution towards managing the risks and potential costs of climate change.

The analytical framework developed above remains valid, but decisions on priorities must rely on judgements about some factors, and a less than comprehensive information set. Nevertheless, the power of this framework is that the vulnerability and importance of some activities can be readily identified with a reasonable degree of confidence, even with a minimal information set. It also points to the types of information that need to be gathered to facilitate further decisions on national adaptation needs and resource allocation down the track.

Importantly, an efficient response to climate change will involve all levels of government in Australia and private sector engagement. Uncertainties, misunderstandings and mixed messages about the future implications of climate change for Australia can be a powerful disincentive to adaptation planning and action. Government has an important leadership role to play in this area — but if the economy is to adjust efficiently to the ongoing and future implications of climate change, it is leadership that private decision makers and owners of important assets must be prepared to emulate and follow.

This report examines these issues in greater detail, and advances recommendations and options for addressing key climate risks and vulnerabilities under the National Climate Change Adaptation Programme.

1.2 Acknowledging Australian Government interests

An important function of this report is to identify how climate change may affect the capacity of the Australian Government to achieve its objectives. This may happen if stated Australian Government policies or specific Australian Government programs are likely to be affected by the impacts of climate change, or if climate change impacts are likely to impose costs on the Australian Government. Priorities for the National Climate Change Adaptation Programme will need to take these factors into account.

1.3 Methodology

This report employs the following basic methodology in identifying possible priorities for the National Climate Change Adaptation Programme and highlighting key issues for further consideration by government.

First, 'candidate' priorities are identified by a combination of literature reviews and the stakeholder consultations described earlier. Note that priorities for a National Climate Change Adaptation Programme may be either sectors or regions, and often efforts in these areas need to be underpinned by processes and mechanisms that will enable activities to be coordinated and ensure that new information and changing circumstances are taken into account.

Second, these 'candidates' are analysed using the framework set out in Table 1.1 — again drawing on consultations and published work. As noted above, this analysis is limited by gaps, sometimes significant, in the available information. However, it is possible to make some reasonable judgements in this area — certainly enough to initiate a research exercise focused around important social and economic assets and identifying key information needed to fuel continuing refinement of the research and policy development exercise. Australian Government programs and policies that may be particularly affected by the impacts of climate change, and should have strategic links to the climate change and adaptation agenda, are also identified.

Stakeholder consultations in all Australian capital cities during August and September 2004, which were focused around a previously circulated issues paper, have been a key feature of this investigative work.

Finally, some conclusions are drawn about possible priorities for the National Climate Change Adaptation Programme.

1.4 Report structure

The remainder of this report is structured to apply the methodology outlined above by drawing on published materials and stakeholder input. It provides an overview of current knowledge but, importantly, also addresses areas of uncertainty and ongoing effort.

Based on a literature review and stakeholder analysis nine sectors and seven regions were identified as 'candidate' priorities.

The candidate sectors were: agriculture, biodiversity, buildings and settlements, energy, tourism, human health, forestry, water supply, and fisheries.

The candidate regions were: the Murray–Darling Basin, rangeland communities, the Cairns–Great Barrier Reef region, coastal and central Queensland, south–west Western Australia, Alpine regions and Far Northern Australia.

Chapter 2 examines **climate exposure.** It overviews current thinking on global climate change and addresses many of the uncertainties and misunderstandings often associated with climate science. It highlights the development of scientific thinking on the threat posed to the Earth's climate systems by rising greenhouse gas concentrations, and the growing confirmation of this threat as scientific analysis progresses.

Chapter 3 explores aspects of Australia's current climate **sensitivity** and existing advice on the potential challenges that climate change might represent for important sectors and systems — both human and natural. These vulnerability studies provide an insight to the types of pressures that might be experienced in other centres and confront activities that, as yet, have not become a focus for researchers and policymakers.

Chapter 4 examines regional dimensions of potential climate **impact**. Climate change and associated risks can vary widely across the continent, and will impact on resident industries and systems in different ways. Communities depend on a range of interwoven systems and vulnerability in one system can have knock on effects for others. Stakeholder discussions also form an important backdrop and supplement to this chapter. Common stakeholder perspectives on climate vulnerability and planning needs are also discussed in this chapter.

The final chapter builds on earlier work, focussing on the policy implications of the discussions and analysis that underpin this study. **Chapter 5** offers an assessment of policy perspectives on **adaptation** to climate change for both human and biological systems, and discusses decision and priority setting frameworks for advancing research, policy and efficient outcomes in this area, taking account of current uncertainties, knowledge gaps and stakeholder needs.

Chapter 2

The state of climate change science

The potential for changes in atmospheric composition — in particular with respect to gases that strongly absorb infrared radiation, so–called 'greenhouse gases' — has been known for more than 100 years. However, it was not until observations commenced in the 1950s that scientists demonstrated that the concentration of carbon dioxide, a key greenhouse gas, was increasing. This led to growing research activities aimed at understanding both the cause of that increase, and its potential to impact on the climate of the earth. In 1985, the global research community prepared a statement that was intended to announce to the wider population that this research, although still quite incomplete, was sufficiently compelling to warrant that the issue of climate change should be considered as a critical issue to the global community.[3]

The scientific understanding of the climate system has advanced enormously since that statement, particularly within the last decade. This has had much to do with the realisation by the scientific community that there is a potential for the increase of greenhouse gases in the atmosphere to shift the climate of the world — and in doing so, create significant threats to human and natural ecosystems and function.

2.1 The IPCC Third Assessment Report

Periodic assessments of climate change and its impact on human and natural ecosystems have been published by the Intergovernmental Panel on Climate Change (IPCC) in 1990, 1996 and 2001,[4] or the First, Second and Third Assessment Reports, respectively. While the science reported in these documents is voluminous and not possible to fully summarise here, the latest IPCC report, the Third Assessment Report made the following underlying points :

- the planet has warmed;
- the composition of the atmosphere is continuing to change;
- models of the climate system have greatly improved;
- much of the observed warming of the last century was due to greenhouse gases;

3 Villach 1986, *The Role of Carbon Dioxide and Other Greenhouse Gases in Climate Variation and Associated Impacts,* Conference Statement for the Second UNEP/WMO/ICSU Assessment Meeting, Villach, WMO Bull: Austria 35, pp 130-134.

4 See: IPCC (J. Houghton, Y. Ding, D. Griggs, M. Noguer, P. van der Linden, and D. Xiaosu (eds)) 2001a, *Climate Change 2001: The Scientific Basis,* Contribution of the Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change, World Meteorological Organisation and United Nations Environment Programme, Intergovernmental Panel on Climate Change, Cambridge University Press: Cambridge, p 944; IPCC (J. McCarthy, O. Canziani, N. Leary, D. Dokken and K. White (eds)) 2001b, *Climate Change 2001: Impacts, Adaptation and Vulnerability,* Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change, World Meteorological Organisation and United Nations Environment Programme, Cambridge University Press: Cambridge, p 1032; IPCC (B. Metz, O. Davidson, R. Swart and J. Pan (eds)) 2001c, *Climate Change 2001: Mitigation,* Contribution of Working Group III to the Third Assessment Report of the Intergovernmental Panel on Climate Change, World Meteorological Organisation and United Nations Environment Programme, Cambridge University Press: Cambridge, p 700; IPCC 2001d, *Climate Change 2001: The Scientific Basis. Summary for Policymakers,* A report of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change, World Meteorological Organisation, Geneva: United Nations Environment Programme, IPPC: Nairobi, p 98; and IPCC 2002e, *Climate Change 2001. Synthesis Report,* Contributions of Working Groups I, II and III to the Third Assessment Report of the Intergovernmental Panel on Climate Change, World Meteorological Organisation and United Nations Environment Programme, Cambridge University Press: Cambridge, p 397.

- greenhouse gases will continue to rise through the 21st century; and
- climate change will continue through the 21st century.

We now consider each of these points in turn.

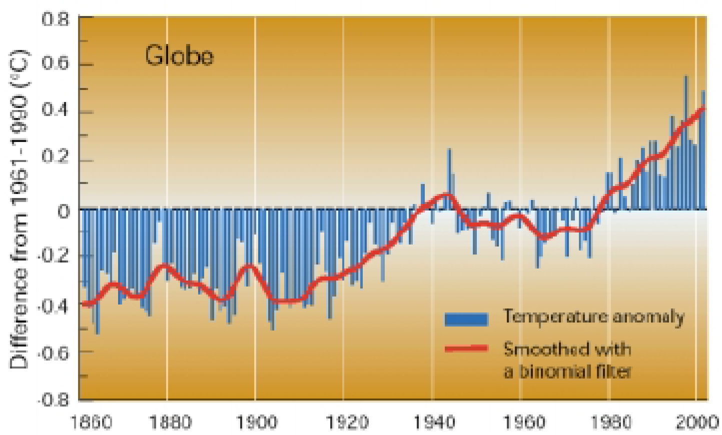
The planet has warmed

The average global surface temperature has increased by about 0.6°C over the past century. This observation is based on careful analysis (integrity of the instrument exposure and lack of changes to that exposure) of climatological observations taken at weather stations around the world (Figure 2.1). This finding is supported by oceanic observations including evidence of warming through the first 1,000 meters of the major ocean basins, and other changes related to temperature changes, such as diminution of sea–ice extent and thickness, recession of glaciers and reduced stream flow. Additionally, associated with this general warming, scientists have observed:

- an increase in global extreme maximum temperatures;
- an increase in global extreme minimum temperatures;
- a decrease in the number of extreme low temperature days; and
- an increase in extreme precipitation.[5]

Figure 2.1

GLOBAL TEMPERATURES, 1860 — 2000



Source: Hadley Centre for Climate Prediction and Research.

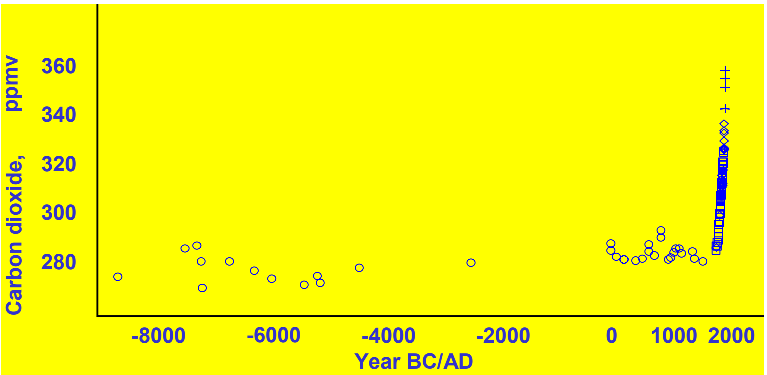
The composition of the atmosphere is continuing to change

The Third Assessment Report also finds that the composition of the atmosphere is continuing to change. This is particularly a function of the increased proportion of the main anthropogenically–modified greenhouse gas: carbon dioxide (Figure 2.2). However, it is also due to changes to the concentrations and distributions of atmospheric dust, which are also important in the climate system.

[5] P. Frich, L. V. Alexander, P. Della-Marta, B. Gleason, M. Haylock, A. M. G. Klein Tank and T. Peterson 2002, *Observed coherent changes in climatic extremes during the second half of the twentieth century,* Climate Res. 19, pp 193-212.

Figure 2.2

CHANGE IN CARBON DIOXIDE CONCENTRATION OVER THE PAST 10,000 YEARS



Source: Change in the concentration of carbon dioxide over the past 10,000 years as observed in dated air trapped in Antarctica ice (symbols) and measured at the Cape Grim Observatory (red line). Data from Etheridge et al. 1996, and MacFarling and Etheridge, CSIRO Atmospheric Research (personal communication).

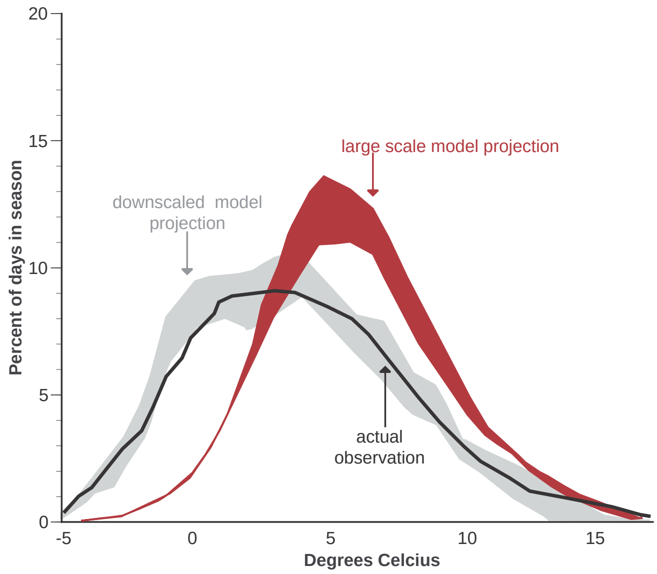
Models of the climate system have greatly improved

The Third Assessment Report's findings support the view that models of the climate system have improved. This is important because it is not possible to perform laboratory experiments to elucidate how the climate of the earth — at either a global or regional scale — could possibly respond to continued changes to levels of greenhouse gases in the atmosphere. In this way it is analogous to landing someone on the moon: the science community needs to understand *all* of the key physical and dynamical processes of the climate system, write equations to represent these processes, and solve these equations using a computer in order to understand, with confidence, what will happen in the future for prescribed levels of gases. To do this, climate models have been developed by a limited number of research groups around the world. These models generate the current climate in enormous detail without depending on the input of meteorological data, representing the interactions of the atmosphere, oceans, cryosphere and biosphere at high resolution. Using the climate models scientists are able to get a reasonable picture of what might happen in the future if greenhouse gas concentrations were to increase. Thus, as these models are improved, the science community's understanding of the potential impact climate change will also increase. While the models still have shortcomings, there has been enormous progress and the findings of climate models are considered to be far more robust than projections made five to ten years ago.

However, one of the many remaining issues with the application of climate models is that they generally calculate climatic conditions at space scales too coarse to be of direct use to individual business planners. Research into improving the resolution of climate models continues and recent developments in downscaling techniques is promising to partially overcome this problem. For example, consider Figure 2.3. This figure shows the frequency of occurrence minimum temperature at Bendigo, Victoria in springtime as estimated by different climate models and as observed over time. The range of results obtained directly from the *large–scale* climate models are shown in red. Results using the new techniques of *downscaling* model outputs are shown in blue. The actual, *observed* temperatures are shown in black.

Figure 2.3

COMPARING MODEL RESULTS WITH OBSERVED DATA: THE FREQUENCY OF OCCURRENCE OF MINIMUM TEMPERATURE AT BENDIGO, VICTORIA



Source: B. Timbal, personal communication. (For details of the approach used, see B. Timbal and B.J. McAvaney 2001, *An analogue based method to downscale surface air temperature: Application for Australia*, Climate Dynamics, 17, pp 947–963.

As the figure shows, models with the new, downscaling capability are more accurately representing the occurrence of minimum temperatures for the area.

Much of the observed warming of the last century was due to greenhouse gases

The climate of the earth has always varied on all time–scales: from year–to–year, decade–to–decade, and over millions of years. There are many causes of these variations. Changes in climate patterns may be *externally* driven — such as by relative planetary positions, changes to solar energy output, the earth's orbital orientation or asteroid impacts — or they may be *internally* driven — such as by volcanism, adjustments to ice sheets, or changes in terrestrial biota. Changes in the atmospheric gas composition have always been one of the many factors influencing climate patterns.

The question is therefore not whether these many influences have existed, or whether these influences will continue to impact on climate patterns in the future, but what is the probability that of any of these influences — including changes to the composition of the atmosphere — will cause substantive and prolonged changes to the climate in, say, the next 50 to 100 years. Risk assessments have shown clearly that the high probability of increased greenhouse gas concentrations, coupled with the significant magnitude of their calculated influence on the climate, means that the increase in greenhouse gas concentrations in the atmosphere will likely be the main cause of climate changes through this century.

Although this conclusion was drawn independently of observations, confidence in this general conclusion has been strengthened with additional data collection and analysis in the past decade. Research has identified changes in the observational record that support this conclusion and furthermore, scientific studies have been able to convincingly attribute changes in the observational record to greenhouse gases and not to other potential influences on climate. Such studies strongly implicate increasing greenhouse–gas concentration as the most probable cause of planetary warming in the second part of the past century, with some influence of volcanic eruptions, aerosol (dust) concentrations and solar activity in the first part of that century.[6]

Greenhouse gases will continue to rise through the 21st century

The most significant anthropogenically–influenced greenhouse gas is carbon dioxide. This gas is produced as the direct result of the combustion of fossil fuels. The following factors suggest that greenhouse gases may increase in the future:

- about two billion people do not have access to substantial levels of energy that could possibly enhance their quality of life, and are expected to aspire to lifestyles that would increase their energy usage;
- in the first half of the 21st century, the world's population is expected to increase by perhaps a further two billion;
- parts of the developed world are still struggling to decouple growth in energy usage from economic growth; and.
- the developed world has already invested huge amounts of capital in existing fossil–fuel based energy systems. Any transition to new energy systems will require leadership courage and the community–wide weighing of investments lost against costs avoided.

For these reasons it is difficult to be optimistic about a rapid reduction of global emissions; indeed these factors suggest that greenhouse gas emissions will likely continue to rise and possibly accelerate.

Complicating this increase in greenhouse gas emissions is the 'life' of greenhouse gases in the atmosphere. The effective lifetime of carbon dioxide in the atmosphere is around 80 years. Thus, in order to stabilise concentrations of this gas in the atmosphere, quite massive reductions in emissions are required.

Climate change will continue through the 21st century

On the basis of this, the IPCC has concluded that it is likely that carbon dioxide concentrations will not be stabilised in the atmosphere for several decades into this century and therefore climate patterns will continue to change.

[6] F. G. Lambert, P. A. Stott , M. R. Allen and M. A. Palmer 2004, *Detection and attribution of changes in 20th century land precipitation,* Geophys.Res.Letters,. 31 L10203-6; P. W. Thorne, P. D. Jones, S. F. B. Tett, M. R. Allen, D. E. Parker, P. A. Stott, G. S. Jones, T. J. U. Osborn and T. D. Davies 2003, *Probable causes of late twentieth century tropospheric temperature trends,* Climate Dynamics, 21 pp 573-591; Braganza 2004, *Simple indices of global climate variability and change II: Attribution of climate changes during the twentieth century,* Climate Dynamics 22, pp 823-838; and P. Stott 2003, *Attribution of regional-scale temperature changes to anthropogenic and natural causes,* Geophys.Res.Letters, pp 1729-31.

The question of how much the climate will change is, however, less certain. This is because the exact trajectory of emissions into the future remains uncertain and difficult to predict. To explain: in 2001, several different climate models were used to project a possible range of possible global temperature trajectories to 2100. These models used inputs derived from IPCC emission scenarios — 'what if' scenarios based on different technological and socio–economic assumptions, such as possible rates of technological change or increases in world income. The climate models projected a global–average warming of between 1.4°C to 5.8°C by the year 2100. This is a wide range of temperature outcomes, and would imply significantly different levels of climate change. About half of this range stems from behavioural uncertainty — such as the range of possible future emission scenarios, which are dependent on assumptions about demographic and technological changes as well as economic rates of growth. The other half is due to scientific uncertainty — that is, different assumed patterns of warming between climate models.

With these caveats in mind, it is possible to examine the general projections of climate models. Climate changes that are expected to increase in the 21st century include:

- while the models project a global–average increase in rainfall and evaporation (a stronger hydrological cycle), this will vary by region. For example, the high latitudes are projected to become wetter, while the middle latitudes are projected to become drier;
- rainfall intensity is projected to increase;
- frosts are projected to occur less often;
- heatwaves are projected to occur more often;
- in some regions, the climate models project more droughts;
- the models also generally project tropical cyclones to become more intense for some areas of the globe; and
- global–average sea–levels are projected to rise by 9 to 88 cm by 2100.

2.2 Scientific developments since the Third Assessment Report (2001)

This section discusses a number of messages contained within the IPCC Third Assessment Report that have been debated by the science community as well as key issues that have arisen since the publication of the report in 2001. This discussion is not intended to be exhaustive, but rather to identify some of the emerging issues and their potential impact on climate change discussions by the wider community.

Significant change can be 'small'

A serious issue with respect to response to climate change is the impression held by the population at large that changes to planetary mean temperature of a few degrees are of little consequence. This might be expected since daily and seasonal variations of temperature are of the order of 10°C, making the warming of the past century (0.6°C) or even anticipated for this coming century (between roughly 1°C to 6°C) seem small, and even in some cases desirable. What is poorly understood is that the year–to–year variation of the planetary mean temperature is around *a few tenths of a degree,* and is of a similar magnitude even on a decadal timescale.

Many climate scientists recognise that the planet has only warmed around 5°C between the last glacial maximum (around 20,000 years ago) to the current interglacial temperatures. This 5°C increase has brought about a major redistribution of ecosystems, as well as extinctions and the emergence of new species. An alternative perspective is that during this last century, anthropogenic activities account for *ten per cent of this long–term change* — and further, that anticipated changes this century are expected to be between about 20 and 100 per cent. To some, this is regarded as significant. For example, earlier this year, US Climate Advisor, James Hansen concluded that '…we are closer to dangerous anthropogenic interference than is generally realized…'[7]

Climate models are becoming increasingly robust

One of the important outcomes from the investment in climate research prompted by concern over climate change since the Third Assessment Report is the improvement in our understanding of the climate system and in our ability to model it. This in turn has markedly improved capacity to predict short–term climate variations (season–to–season). Whilst climate models are still rudimentary and the value of their projections dependant on what region and season is being considered, the skills in such predictions have yet to be fully implemented into natural resource management systems as a method of producing greater productivity and reducing vulnerability to variation of climate. Opportunities exist particularly within the areas of water and agricultural resource management.

Investment in climate research has also highlighted the issue of variability — that the climate is variable, especially in Australia, and that in general recorded climatological data provide little information about the potential for longer term (return periods of 100 year or more) events. Building improved knowledge of this variability into management systems and incorporating with this a better understanding of the impact of climate change itself is the primary research and application challenge ahead. What is certain is that the concept of statistically constant climatic conditions is no longer an appropriate approach to risk management related to climatic issues.

Scientific uncertainties, vulnerability and enhanced risk

Not all is known about climate change and variability. This limits the accuracy of climate model projections. New knowledge in the next decade or so is likely to improve our ability to reduce the currently wide range of possible 'climate futures' based on IPCC scenario projections. However, in a complex system in which there is strong human intervention and responsiveness, it is reasonable to assert that the future is largely unpredictable. Climate scientists have deliberately chosen to speak about *projections* of the future, where anticipated changes in key parameters — such as human treatment of the energy demands and discovery of technological options — are assumed, but not known with any certainty. It is quite common, however, for such projections to be misinterpreted as *predictions*, which are probabilistic estimates of the likelihood that an outcome might eventuate. There is a need for wider appreciation that the role of science is not necessarily about prediction, but about the provision of options and possible outcomes described by the physical realities of the system.

[7] J. Hansen 2004, *Defusing the Global Warming Time Bomb,* Scientific American, March, pp 68-77.

2.3 Emerging and unresolved scientific issues

As argued above, significant aspects of the science of climate change are still evolving. Depending on how this knowledge develops in the coming years, perceptions about the imperative for adaptation and mitigative responses will evolve, as will views of what policy options may maximise resilience of communities and companies.

This section examines some of the scientific issues that remain unresolved and that might impact on decisions made about climate change both today and tomorrow. The responses of humans to the issue of climate change will relate to this emerging science, to observational evidence of impacts, and to the relative costs and benefits of adaptive and mitigative responses.

What is dangerous?

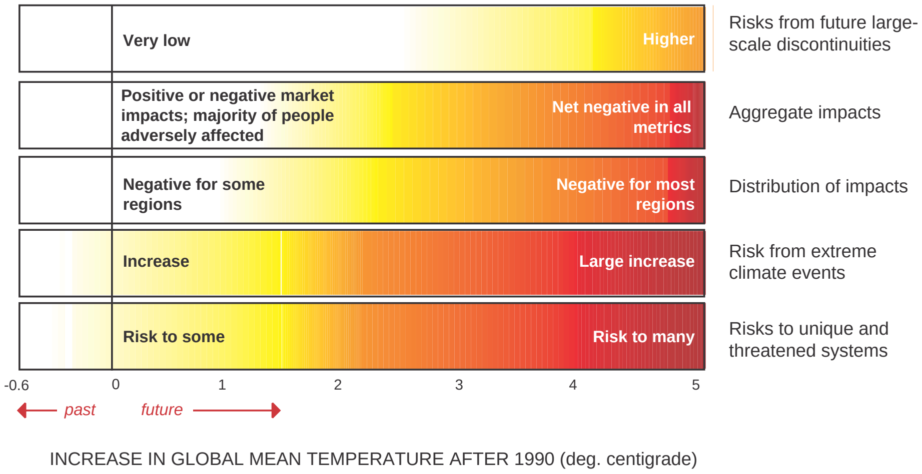
It has been argued that 'small changes' in climate can have significant impacts. This results from a combination of factors, including:

- the existence of narrow thresholds for response to change for some species/ecosystems;
- the complexity of interactions that determine current ecosystem function and balance;
- the non–linearity of response functions, such as the dependence of damage on wind speed; and
- the existence of reinforcing factors that exacerbate the impact of any one factor (the example of sea level, low pressure and wind speed).

How much change might bring about a material change in climate patterns that communities of the world would regard as 'dangerous'? The answer to what is 'dangerous' is dependent on the development of knowledge about the factors driving changes in climate and the integration of this knowledge into a framework that reflects what humans are prepared and not prepared to accept as options for the future. The IPCC provides a preliminary indication of how the risk of certain adverse climate effects is likely to increase with rising mean global temperature levels (see Figure 2.4).

Figure 2.4

IMPACTS OF OR RISKS FROM CLIMATE CHANGE, BY REASON FOR CONCERN



Source: IPCC 2001, *Third Assessment Report*, TS12. Note: Each row corresponds to a reason for concern, and shades correspond to severity of impact or risk. White means no or virtually neutral impact or risk, yellow means somewhat negative impacts or low risks, and red means more negative impacts or higher risks. Global–averaged temperatures in the 20th century increased by 0.6°C and led to some impacts. Impacts are plotted against increases in global mean temperature after 1990. This figure addresses only how impacts or risks change as thresholds of increases in global mean temperature are crossed, not how impacts or risks change at different rates of change in climate. These temperatures should be taken as approximate indications of impacts, not as absolute thresholds.

Thus far, isolated studies of coral reefs, coastal inundation, water resources and other natural systems have provided some ideas about vulnerability to particular changes in climate. However more knowledge is needed and is likely to emerge through this decade. As is does, it will provide a more precise definition of the degree of climate change that is regarded as ‘acceptable’ and within the realms of reasonable adaptive change. It will also define what is outside of this range. What this level of change will be is currently unquantifiable, but the probability that it will be at the lower rather than the higher end of the IPCC projections of climate change for this century is too large to be prudently ignored. If that were to be the case, this would impose greater demands on both adaptation and mitigative policy responses.

Climate change need not be gradual; a number of abrupt, non–linear changes in climate are known to have occurred in the past and science indicates that enhanced greenhouse warming could lead to such changes in the next few decades. The stepwise decline in rainfall observed in South West Western Australia in the period 1967–72 (which has still not reversed) is an example of such an abrupt, non–linear change; although the causes of this change cannot be stated with confidence there is evidence that the enhanced greenhouse effect was a contributing factor. Climate models identify the risk of such abrupt non–linear changes but are less successful in identifying when they may occur. Box 2.1 itemises some of the large–scale abrupt climate shifts that may occur as a result of the enhanced greenhouse effect. The likelihood of these events occurring in the next 30 to 50 years varies, but all are scientifically plausible. The capacity for radical theory to become the new frontier of accepted physical science is not without precedent in the history of scientific thought.

There is a spectrum of issues in climate change ranging from those that are certain (e.g. the concentration of carbon dioxide is going up; carbon dioxide does interfere with the radiative balance of the atmosphere; the planet has and will warm, etc) to things that are almost certain (e.g. tropical storms will be more intense) to events and outcomes that are clearly uncertain (e.g. the rapidity of changes to the dynamics of the ice sheets and more rapid sea–level rises), but which would have a radical impact on the planet. Risk assessments need to take account of the prospect of these ‘high end’ changes and their implications if they come to pass. Such assessments must also take account of the possibility that, as our understanding of climate science improves, the trigger conditions for such events might be closer than currently anticipated.

Box 2.1

POTENTIAL 'HIGH END' IMPLICATIONS OF CONTINUED GLOBAL WARMING

Scientists noted recently that we might have less time to combat global warming than we thought. Measurements taken in Hawaii show atmospheric carbon dioxide levels have risen sharply, and inexplicably, in the past two years. Although it is too early to confirm a definite upward trend, the results came as an unwelcome surprise.

John Schellnhuber, research director at the Tyndall Centre for Climate Change Research in Britain, points to numerous systems where global warming could produce sudden and dramatic environmental damage. The level of uncertainty remains very high.

Amazon forest

The size of Western Europe, the Amazon forest is one of the most biodiverse regions on Earth. Models suggest that, with global warming, will come a drop in Amazonian rainfall, leading to the gradual death of the forest and subsequent collapse of the myriad ecosystems it supports. As the trees die off, they will fall and rot, releasing carbon dioxide. In the worst-–case scenario, the quantities of carbon dioxide emitted could be similar in magnitude to the 20th century's total fossil fuel output.

The monsoon

During March and April, the Indian subcontinent begins to heat up. The hot land produces a sharp temperature gradient between the land and sea that causes an abrupt reversal of the winds from seaward to landward.

As the winds strike the Himalayas and are deflected upwards, they create a low pressure system, forcing rain clouds to release their stores of water. While the monsoon season can cause incredible flood damage, local populations are largely adapted to, and to some extent reliant on, the weather.

If global warming has the expected effect of heating India even more, the monsoon season could become far more severe. However, pollution in the region could make rain droplets smaller, diminishing overall rainfall. Pollution can also increase the reflectivity of clouds, preventing the ground heating up so much. These factors would weaken the monsoon, causing havoc for Indian agriculture, with serious consequences for food production.

Methane clathrates

Deep within the Siberian permafrost and ocean floor sediments lie vast deposits of gas-–filled ice called methane clathrates. At Siberian temperatures, or under the weight of icy oceans, the clathrates are stable. But as global warming takes effect, the icy crystals that clutch the gas could rupture, releasing it into the oceans and atmosphere. According to the United States Geological Survey, some 10 trillion to 11 trillion tonnes of carbon are locked up in clathrates in ocean floor deposits, the equivalent of 20 times the known reserves of natural gas. If released into the atmosphere, methane from the clathrates could exacerbate global warming by up to 25 per cent.

Tibetan plateau

Spanning a quarter of China's huge land mass is the Tibetan plateau. Because the region is permanently under snow and ice, it acts like a giant mirror, reflecting the sun's rays back into space. The effect is to keep a lid on global warming, at least locally, as the darker soils are unable to bask in the sun's radiation and increase in temperature.

In a warmer world, the white of the Tibetan plateau will slowly turn to brown and grey as the snow retreats to reveal the ground beneath. As the ground warms, melting will accelerate. Tibet will become a much warmer place.

North Atlantic current

The North Atlantic current is one of the strongest ocean currents in the world. It works like a conveyor belt. Surface water in the North Atlantic is first cooled by westerly winds from North America, making the water denser and saltier so it sinks to the ocean floor before moving towards the equator. Driven by winds and replacing the cold water moving south, warm water from the Gulf of Mexico moves upward into the Atlantic.

The effect of the current on climate is dramatic. It brings to Europe the equivalent of 100,000 large power stations' worth of free heating, propping up temperatures by more than 10C in some parts. Global warming could change all that, though not quickly. Computer models predict that as global warming increases, so will rainfall in the North Atlantic. Gradually the heavier rains will dilute the sea water and make it less likely to sink, a process that could eventually bring the whole conveyor to a halt over the course of a few decades. (This issue is taken up in the discussion of thermohaline circulation provided in this chapter.)

Ozone hole

Scientists now generally agree that global warming may drastically amplify the power of ozone-—destroying chemicals, which linger in the stratosphere for decades. At high altitude, ozone acts as a shield against the sun's damaging radiation. Global warming, while heating the lower atmosphere, can lead to cooling in the stratosphere where the ozone layer forms. Cooling this band of air has a complex knock-—on effect, disrupting a chemical process that prevents ozone from breaking down. The result is a loss of ozone, increasing the risk of skin cancer and blindness. Although the ozone hole is often associated with Antarctica and Australia, ozone loss because of global warming could lead to holes over other parts of the world.

West Antarctic icesheet

The giant West Antarctic icesheet won't melt in the near future -— the ice is up to a kilometre thick -— but two years ago a vast chunk, the Larsen B iceshelf, broke off the eastern side of the Antarctic peninsula and fragmented into icebergs. In just 35 days, about 3250 square kilometres of ice were lost. The shelf is now roughly 40 per cent of the size at which it had previously stabilised. Some scientists predict that the rest of the sheet could feel the force of global warming quickly. Should the entire sheet melt, it is estimated the sea level around the world would rise by more than six metres.

Salinity valves

In some parts of the world, local geography conspires to pinch the waters between adjacent seas into separate bodies of water. If one is saltier than the other, a flux of salt, nutrients and oxygen can be set up across the gap, producing what scientists refer to as a salinity valve. Probably the most significant salinity valve is the Strait of Gibraltar, acting as a pinch between the Mediterranean and the North Atlantic Ocean. The areas around the valves give rise to unique ecosystems that are highly adapted to local conditions. If conditions around salinity valves change rapidly, those ecosystems may not be able to adapt quickly enough to survive.

El Nino

The disruption caused by El Nino is well known, from droughts in Asia and Australia to flooding in regions such as Ecuador and northern Peru. The term refers to a general warming of the central and Asian Pacific, which causes a major shift in weather patterns. El Ninos are already somewhat erratic, occurring every two to seven years, but some models say global warming may make these events not only more severe but more frequent.

The impact on agriculture and food production could be serious. Indonesia, the Philippines, South-—East Asia and eastern Australia (see text) could face damaging droughts, while the heavy rains and flooding could cause problems for the north-—western regions of South America.

The Antarctic circumpolar current

Some scientists believe the Antarctic circumpolar current is the most significant on the planet. It swirls 140 million cubic metres of water around Antarctica every second, mixing water from the Pacific, Atlantic and Indian oceans as it goes. The current taps into another circulation that causes cold surface water to sink while warmer water rises, bringing with it vital nutrients from dead plankton and other marine life on the ocean floor. Global warming is expected to produce more rainfall over the poles, which could slow the rise of nutrients for dispersal by the Atlantic circumpolar current, with potentially significant impacts on the marine food chain.

Greenland icesheet

The Greenland icesheet holds about 2.6 cubic kilometres of fresh water -— about 6 per cent of the planet's supply. It is imperative that this water remains frozen. If global warming causes temperatures to rise by more than about 3C, Greenland is likely to begin a slow thaw, steadily releasing all that water -— now resting on land -— into the North Atlantic Ocean. Climate models suggest that a temperature increase of about 8C could cause the Greenland icesheet to disappear almost entirely -— a thaw that would lead to a seven-—metre rise in sea levels.

Source: The Guardian, ‘World’s Achilles Heels’, an article based on an interview with Professor John Schellnhuber, Research Director of the Tyndall Centre for Climate Change (UK) and reproduced in the Sydney Morning Herald, 26 October 2004. Edited version shown above.

Thermohaline circulation

Observational evidence shows the formation of deep oceanic water at high latitudes of the North Atlantic and Southern Oceans has slowed slightly over recent decades. These observations support the findings of a number of climate models that show that as the warming of the oceanic surface continues, ocean mixing stabilises and bottom water formation is reduced — leading to a slowing of the thermohaline circulation.

This is highly significant as this process currently removes around two giga-tonnes of carbon from the atmosphere each year, recycling it deep in the ocean. Without it, atmospheric carbon dioxide (and thus climate change) would be increasing around 30 per cent faster than it is. This same mechanism also carries oxygenated water in the oceans and thus supports deep ocean life. Finally, it is the mechanism that brings warmer, low-latitude water from the Gulf Stream northwards and strongly influences the climate of Western Europe.

Each of these functions is alone an important component of the earth's system and any significant change might be regarded as undesirable if not untenable. Current climate system models simulate a reduction in this circulation as the planet warms, however these models are not sufficiently developed to be certain about the degree to which this circulation might change through this century. Again, in this context it is not whether future science will confirm that this change to oceanic circulation constitutes a change that is 'dangerous', but rather that, sometime, perhaps in the next decade, this science will be sufficiently developed to provide answers with greater certainty. There is a finite risk that this will impact on the imperative to prevent change, or on the magnitude of change at both the global and regional level.

Biosphere feedback

Studies of the global carbon budget have shown, somewhat surprisingly, that the global biosphere has been a net sink for carbon over the past two decades of about two giga–tonnes of carbon per year — significantly slowing the rate of growth of carbon dioxide in the atmosphere.

There is reason to believe that this net absorption of carbon by the biosphere may not be sustainable beyond the next one or two decades — at which time more carbon dioxide will accumulate in the atmosphere. There is currently an insufficient understanding of this phenomenon to be sure if and when this may occur, but again it represents a risk that may impact on the outcomes for climate change in the future and therefore on decisions that humans will need to make about how to respond.

Aerosols and clouds

One of the weaknesses in current modelling of the global climate system is in the representation of aerosols (dust). Aerosols have the capacity to impact on climate in a number of ways. Directly, they intercept both solar and infrared radiation arriving at or emitted from the earth. There is existing evidence — at least regionally, where significant local air quality impacts are seen — that this has somewhat *countered* the warming effects of greenhouse gases, perhaps by reflecting sunlight back to space. However, not all aerosols have the same physical and chemical properties or emission distributions, and therefore it is uncertain how each influences regional climate.

Aerosols are also intimately involved in the microphysics of cloud formation (acting as condensation nuclei) — affecting the optical properties of clouds and their propensity to form droplets of a size conducive to precipitation or evaporation.

It remains possible that the sensitivity of the climate system is at the upper end of model results, despite the observed changes in climate being more like the 'average' projection in most models, because the effect of changing levels of greenhouse gases may have in part been masked by the concomitant changes in atmospheric aerosol loading. It is too early to say — developments in this science are likely to impact on our interpretation of future climate prospects over coming years.

Emission scenarios

The emission scenarios that were used to underpin projections of climate change were attempts to represent possible alternative futures that reflect population growth, technological innovations, the bridging of inequities in energy supply across the world, economic development and other factors. They cannot be regarded as predictions, nor can probabilities be ascribed to the likelihood of any one scenario being more likely to represent the future. Furthermore the IPCC scenarios do not include specific measures to reduce greenhouse–gas emissions — any resulting risk will be assessed in the absence of management through mitigation and adaptation.

Thus the IPCC scenarios are not forecasts in the conventional sense, although they are currently the best, most valid way of developing an initial understanding of the risks associated with climate change. Scenarios are excellent tools for contingency planning (what–if analysis) and are important complements to forecasting. Other approaches to constructing possible future emission profiles for assessing risks relevant to adaptation are being explored by a variety of researchers. One example is the proposal by Webster et al[8] for a central case scenario with an uncertainty range.

Castles and Henderson[9] note that the IPCC warming projections are based on greenhouse emissions projections that may be too high because market exchange rates (MER) were used rather than purchasing power parity (PPP) in calculating future world economic growth. However opinions about the impact of failing to adjust for PPP vary widely and range from studies that report no effect[10], to others that report an overestimate of emissions by between 20 and 40 per cent.[11] The point has generated some debate among international experts[12] who point out that long–term emission projections are based on many interdependent driving forces, including economic growth and energy intensity.

[8] Webster et al 2003, *Uncertainty Analysis of Climate Change and Policy Response*, Climate Change, 61, pp 295-320.

[9] I. Castles and D. Henderson 2003, *The IPCC Emissions Scenarios: An economic-Statistical Critique,* Energy and Environment, vol 14.

[10] Holtsmark and Alfsen 2003, *PPP–correction of the IPCC Emissions Scenarios — Does it Matter?,* Discussion Paper 366, Research Department of Statistics Norway.

[11] McKibbin, Pearce and Stagman 2004, *Can the IPCC SRES be Improved?*, Energy and Environment.

[12] See N. Nakicenovic, A. Grübler, S. Gaffin, T.T. Jung, T. Kram, T. Morita, H. Pitcher, K. Riahi, M. Schlesinger, P. R. Shukla, D. van Vuuren, G. Davis, L. Michaelis, R. Swart and N. Victor 2003, *IPCC SRES Revisited: A Response,* Energy and Environment, 14; and A. Grübler, N. Nakicenovic, J. Alcamo, G. Davis, J. Fenhann, B. Hare, S. Mori, B. Pepper, H. Pitcher, K. Riahi, H. Rogner, E. La Rovere, A. Sankovski, M. Schlesinger, P.R. Shukla , R. Swart, N. Victor and Jung 2004, *Emissions scenarios: a final response,* Energy and Environment 15, pp 11-24.

For this study the important issue is whether these differences in methods for estimating future emissions have a significant effect on estimated global warming over a period of 30 to 50 years. The effects over this period are likely to be small and the issue can therefore be regarded as a second order one for the purposes of this study. It should be noted that much of the climate change expected over the next 30 to 50 years will be driven by emissions that have already take place.

Developing means to reduce uncertainties about the future of climate change will include ways of developing new emission scenarios that reflect growing knowledge of technology options and social and economic development. It may also provide for the development of probabilities of occurrence for different futures. These will form the framework for risk assessments. The issue of parity price is one matter to be considered in these revisions.

Reality of projections

As it has already been described, it is not possible to predict future climate change, particularly at the regional level, because socio–economic and technical factors that would underpin such a prediction are subject to too many uncertainties.

Yet, such a statement is perhaps overly pessimistic. It glosses over the fact that some parameters of the climate system, including temperature, are likely to be more reliably predicted than others, such as rainfall. It also ignores the fact that prediction is more likely to be possible for some regions than for others, due to the relative complexity of interactions of climate process in different regions.

2.4 Peeling back the uncertainty

Changes in atmospheric composition are historically unprecedented

The precise and direct observation of the concentration of carbon dioxide in the atmosphere commenced in Hawaii and Antarctica during the late 1950s. Several additional monitoring programs commenced just over a decade later, including a CSIRO program of aircraft observations over south–eastern Australia and a continuous monitoring program at the Cape Grim Observatory, Tasmania.[13]

[13] N.W. Tindale, N. Derek and P.J. Fraser (eds.) 2003, *Baseline Atmospheric Program (Australia) 1999-2000,* edited by Bureau of Meteorology and CSIRO Atmospheric Research: Melbourne, Australia, viii, p 110.

Figure 2.5

CARBON DIOXIDE CONCENTRATIONS IN THE ATMOSPHERE: DATA FROM 440,000 YEARS BEFORE PRESENT TO TODAY

Source: Cooperative Research Centre for Greenhouse Accounting.

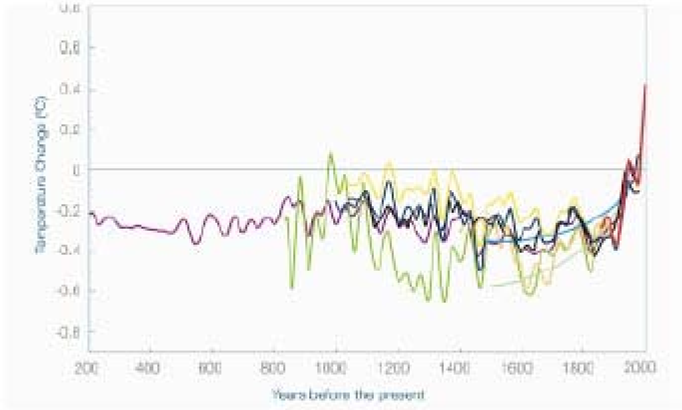
These records have been extended backwards in time through the work of scientists around the world who have developed techniques for the extraction of uncontaminated air from air bubbles trapped in ice or in the air spaces in snow in Antarctica. This latter approach has enabled the precise description of the changing composition of the atmosphere with respect to the greenhouse gases. The French data, recently updated,[14] now provides confirmation that current carbon dioxide levels are higher that they have been in 440,000 years (Figure 2.5 above). Geological evidence suggests that this may also be the case over the past 20 million years.

Similarly, precision measurements of the temperature of the earth's surface also exist for most locations, though only for the past century or so. Efforts to extend the record back in time have involved seeking proxy measures of temperature, such a tree–ring growth or sedimentation rates. Several groups have now attempted to reconstruct the earth's temperature in order to show that the current planetary temperatures are unprecedented over the past 2,000 years.

[14] Wolff et al. *Nature,* 429, pp 823-628.

Figure 2.6

TEMPERATURE OF THE EARTH'S SURFACE OVER THE PAST 1,800 YEARS



Source: NOAA 2003, *Global surface temperatures over the past two millennia*, US National Oceanic and Atmospheric Administration. Note: This graph shows the temperature of the earth's surface over the past 1,800 years as determined from eight separate studies by several institutions using proxy temperature data. The red line shows the directly observed global average temperatures since the mid–1800s.

Chaotic systems and the predictive power of climate science

The climate of the earth has always varied on all time scales: from year–to–year, decade–to–decade, and over millions of years. At first observation, these variations might appear to be random or chaotic. However there are many reasonably well understood reasons for these variations. Many of the longer time–scale variations relate to planetary position — as the earth and planets change relative position with respect to the sun. Other changes such as the oscillation between ice age and interglacial conditions over the past almost one million years are related to the precession of the earth on its axis. Such changes are generally predictable. Though some catalysts of change happen with such a low probability that it is not reasonable to factor them into climate predictions, they can never be entirely ruled out. For example, being struck by a large meteorite is another possible cause of a significant climate variation — though thankfully, one assigned a low probability of occurrence.

On shorter time scales, the emission of energy from the sun varies with time — though in a non–predictable way — producing decadal variations in planetary temperature that are relatively small and not long–lived. Similarly, on shorter times scales, individual volcanic eruptions can cause changes that generally persist for about two years, which is roughly the time that it takes for dust from the eruption to be removed form the stratosphere. Perhaps the most well recognised year–to–year source of variability is the El Niño–Southern Oscillation (ENSO). ENSO is the physical variation of the state of the atmosphere/oceans that produces the El Niño–La Niña phenomenon of drought and flooding periods. It is measured by the ENSO index, which is the normalised pressure difference between Darwin and Tahiti. The internal dynamics of this short scale phenomenon, unlike some other short term causes of change, are well understood and modelled.

Climate scientists have examined the energy impacts with respect to each of these causes of change — including both short and long term catalysts — and tested the performance of climate models in representing what has been the observed climatic response. In general, there is good agreement between the models and confidence that these models contain most of the relevant physics and internal dynamics to robustly represent the real climate system. Thus, by and large these changes are chaotic in the sense that some of the drivers of change cannot be predicted even though the mechanisms are known and understood.

However, in the context of climate change policy, the question is most frequently asked: "what is the most likely prognosis for the climate in the next 50–100 years?" To answer this question a risk assessment must be made. The assessment involves:

- assessing which of these factors might conceivably change over this period; and
- assessing which are the most significant in terms of the degree of climatic impact.

The answer is that it is highly probable that greenhouse–gas concentrations are going to rise over this time and that the impact of these on the temperature is relatively large. Thus the risk associated with a greenhouse–induced climate change far exceeds the risks from other factors that could potentially influence the climate in this time period.

Capacity to understand and forecast regional climate change is improving

Anticipating the general warming of the planet as a result of projected increases in greenhouse–gas concentrations is a relatively well addressed scientific problem — at a larger scale, the climate models appear robust. However, making such projections at an increasingly smaller scale — which is what is ideally needed to anticipate and understand system vulnerability, as well as plan for adaptive responses — is significantly more difficult. There are three key reasons for this:

- models calculate the climate at a space scale that is partially limited by the computing power available, and this is often at a horizontal resolution of roughly 100 km;
- models may exclude significant regional components of the system (such as narrow coastal currents, local topography or land surface conditions) that cannot be adequately represented in the global model;
- the regional projection of some climatic indicators such as temperature is physically more likely to be projectable than those in which the physics and dynamics are much more complicated — and often non–linear — leading to the potential for distorted representation at the regional level.

In recognition of this various approaches are being explored to relate the climate change projections from global models to regions and locations of interest:

- the process of 'nesting' higher resolution models in the lower resolution global models;
- using distorted grids that allow for greater resolution for sections of the earth's surface that are of special interest ; or

- the process of 'downscaling' whereby statistical methods, based on observational evidence of the relationship between spatially–average and local conditions, are used to transform model–resolution information to local information (an example of this is given in Figure 2.3).

As the science incorporated within the climate models is improved over the coming years and as the computing power available is increased, then there is an expectation that projections at the regional level — for more of the characteristics of the climate system — will become more reliable. However, it is important to note these projections will remain subject to uncertainties about the future level of greenhouse–gas emissions and their accumulation in the atmosphere.

Complete certainty will remain elusive given complexity of climate systems

Even with all of the expected advances in climate science, it is necessary to reiterate that complete certainty of the future is not possible. While science can endeavour to explain the physics and internal dynamics of the climate system at increasingly high resolution, it cannot predict:

- the response of the global community to increasing demands for energy;
- the discovery of new technologies and innovations to meet these needs;
- what will be perceived by the community as 'dangerous' change; or
- the social and political responses to bring about the control of concentration increases in the atmosphere.

All of these factors contribute to our inability to predict future climate change at both the global and regional scales.

However through time, better measures of the probability associated with a change to a particular feature of the climate system are likely to be established. In time these may be used to attribute probabilities to specific climate futures. Similarly wider community attitudes may converge on an understanding of what are unacceptable levels of change and of the actions communities are willing to pursue. However at this stage, it is not possible to investigate these possible futures in more than the most qualitative fashion.

Imperative for planning to adapt to climate change

The imperative to plan for adaptation to anticipate climate change arises because:

- observational evidence exists to show that human and natural systems are vulnerable to existing climate variability and to changes in climate that have occurred through the last 50 years;
- there is a very high probability that further change to the climate will occur through the coming decades, both as natural variability and through greenhouse–gas induced change associated with the ongoing impact of current levels of greenhouse gas in the atmosphere;
- these changes will bring about major changes to the characteristics of the weather systems that are regarded as the 'current' climate — rendering existing coping and management strategies of reduced value; and
- the control of the growth of greenhouse–gases in the atmosphere is very difficult as a result of:
  - the long life–time of carbon dioxide in the atmosphere;

- the difficulties of evolving the energy system to meet growing demands for energy; and
- the difficulties of reducing emissions simultaneously, so that mitigation can only be part of the response strategy.

Building resilience, and thus sustainability, into human and natural systems involves developing the ability to persist and adapt through a combination of attention to prudent precaution, avoidance of vulnerability and to the maintenance of ecological integrity.

Chapter 3

Australia's climate sensitivity

The Australian economy, and the society in which we live, is significantly affected by climate. A number of systems clearly have close linkages to climate conditions; others have a strong reliance on these. Climate and weather events can also influence the communities we live in, our health and other key contributors to quality of life. It is important to understand the dynamics and contributions of these systems, and the pressures they might come under in the future, in investigating the implications of climate change for Australia.

The Australian Greenhouse Office and the CSIRO have been active in promoting continuous improvement in regional climate change analysis for Australia. Yet, as indicated in the previous chapter, difficulties in predicting future emission outcomes mean that scientists cannot be definitive about the climate conditions that will prevail in 30, 50 and 100 years time. Climate change scenarios for Australia have been extensively reported in Pittock 2003. A brief summary is provided in Box 3.1.

Box 3.1

CLIMATE CHANGE IMPLICATIONS FOR AUSTRALIA

Regional climate projections issued by CSIRO in May 2001 included projected changes in Australian temperatures and rainfall based on the results of nine different climate models and a range of future greenhouse gas emission scenarios. Since then, CSIRO have completed a number of regional climate projections for specific States or Territories that update the results of the May 2001 studies, often using a finer scale of spatial resolution or containing additional information about likely changes in extreme events such as heavy rainfall and extreme high temperatures. In addition, a number of regional climate projections have been carried out for the purpose of particular studies. These projections often rely upon a single climate model.

Pittock provides the following summary of these scenarios:

- The results suggest annual average warming over much of inland Australia in the range of 1–6 °C by 2070, and slightly less in coastal regions.
- Rainfall results are more complex regionally and seasonally, but overall they suggest a likelihood of decreasing rainfall over most of Australia (particularly the south–west and the south–east mainland) as the 21st century progresses.
- However, consistent with conclusions in the IPCC's third assessment report, an increase in heavy rainfall is projected, even in regions with small decreases in mean rainfall. This could lead to more droughts and more floods.

Source: Based on B. Pittock (ed) 2003, *Climate Change: An Australian Guide to Science and Potential Impacts*, prepared for the Australian Greenhouse Office: Canberra.

Even as models of the climate system improve, and scientists gain a better understanding of the complex interactions of land, sea and air, uncertainties associated with emission levels — linked to issues of global economic growth and structural change, population and technological change — will continue to mean that decision makers and households must contend with the reality of a range of possible climate outcomes when considering the climate pressures that will impact on them, and the systems they manage, in coming years. These issues form the background to the discussion of climate–induced pressures that follows.

3.1 Climate pressures on industry

Agriculture

Agriculture is important to Australia for many reasons. Economically it accounts for about three per cent of GDP. Socially, it is the lifeblood of many rural communities. Environmentally, agriculturalists are stewards of a large proportion of the Australian landmass.

The 2002-03 drought gave a painful demonstration of the well-known dependence of agriculture on climate. Farm output fell by close to $3 billion and Treasury estimated that GDP was one per cent lower than it would have been had the drought not occurred. Many families and communities experienced hardship.

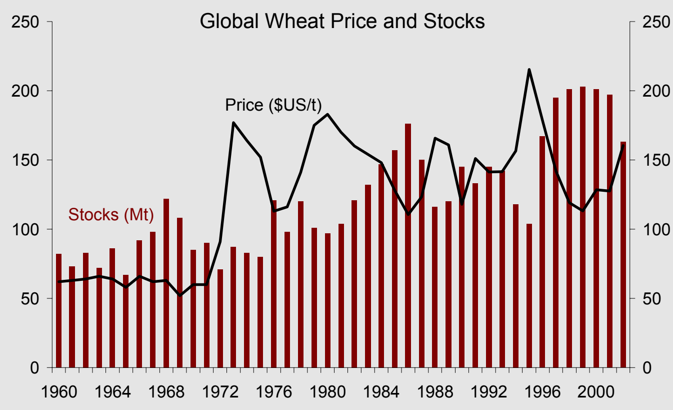
Key climate pressures on agriculture will vary by location through a combination of increasing carbon dioxide levels, increasing temperature, changing precipitation patterns and evaporation rates. Not all agricultural enterprises will be affected by climate change in the same way, and there will be variation by region and by crop. Graduated climate change sensitivity assessments have been conducted for some industries including the wheat,[15] dairy,[16] beef[17] and horticultural[18] industries.

The prosperity of the Australian agricultural industry is also linked to global climatic conditions that influence worldwide production and supply, and hence commodity prices. Commodity prices in turn dictate the incomes that farmers receive from sale of their goods in world markets (see Box 3.1).

Box 3.1

GLOBAL CLIMATIC CONDITIONS AND COMMODITY PRICES

While domestic conditions play a key role in determining Australia's agricultural output, the income that farmers receive is heavily influenced by global commodity prices. These depend on the global production and demand conditions for agricultural commodities. The example below illustrates the inverse relationship that exists between wheat prices and world supply, measured by the availability of wheat stocks.



Source: ABARE 2003c, Australia Commodity Statistics 2003, Canberra; and World Bank 2003, Global Economic Prospects and the Developing Countries 2003, Washington.

[15] The sensitivity of the wheat industry has been examined on a degree by degree basis, showing a threshold at 2° C after which yields and grain quality experience sharp decline. See CSIRO 2001a, op. cit., pp 3-4.

[16] Ibid, p 3.

[17] N. White, R.W. Suthherst, N. Hall N and P. Whish-Wilson 2003, *The Vulnerability of the Australian Beef Industry to Impacts of the Cattle Tick Under Climate Change,* Climatic Change, 61(1-2): pp 157-190.

[18] R.W. Sutherst, B.S. Collyer and T.Yonow 2000, *The Vulnerability of Australian Horticulture to the Queensland Fruit Fly Under Climate Change,* Australian Journal of Agricultural Research, vol 51.

For the purposes of this report, risks associated with climate change impacts are considered for five sub-sectors: extensive livestock, intensive livestock, annual crops (fruits and vegetables), perennial horticulture, and annual broadacre crops.

EXTENSIVE LIVESTOCK INDUSTRY

Vulnerability criterion	Findings
Exposure	The Australian extensive livestock industry is located across a wide range of agro ecological zones that differ significantly in their access to rain-fed and irrigated water. Climate change will leave many regions highly exposed due to increased temperature, reduced annual rainfall or reduced water when needed for plant growth. An increase in the intensity and frequency of extreme events such as drought will limit the capacity to grow productive pastures in some regions. It is also likely that the temperate areas will be more exposed to the impacts of climate change than the tropical grazing lands.
Sensitivity	This industry is relatively sensitive to the impacts of climate change and can be attributed to a number of factors including: heat stress, availability of good quality water, susceptibility to pests and diseases, supply of high quality feed, frequency and number of drought years, and the ability to recover after drought. The impact of elevated CO_2 on plant growth may influence the composition of pastures and reduce their overall quality.
Adaptive capacity	The extensive livestock industry is vulnerable to the impacts of climate change with few adaptive options available across most rainfall zones. The capacity to adapt will largely be through the introduction of drought tolerant pasture species and animal breeds. There is a potential to reduce the risks associated with climate change through access to multiple holdings located in widely different climatic zones. The industry has the potential to maintain high productivity through the use of intensive feedlots to finish stock before sale. The extensive livestock industries located in the more marginal temperate regions of Australia are at greatest risk to the impacts of climate change. Increased pressure on poorly productive pastures could also have serious NRM issues such as increased surface runoff causing soil erosion, and reduced soil water storage leading to further declines in pasture production.
Adverse implications	Extensive livestock industries represent about $8 billion worth or export earnings annually[19]. The industry consists of about 30 million cattle and about 100 million sheep on unimproved rangelands in the northern half of the country and improved rain fed and irrigated pastures in the southern States. Removal of animals from extensive grazing systems could result in the proliferation of invasive weed species. Options for the reuse of grazing land if animals are no longer able to graze it are limited and may result in serious NRM issues. There is some opportunity for native revegetation.
Potential to benefit	Extensive livestock operations have limited capacity to benefit from the impacts of climate change. These impacts will be greatest in the southern States and less obvious in the northern States. Northern grazing pastures may become more productive with more extensive rainfall distribution. Access to new pasture varieties and animal breeds that are tolerant to drought or have a shorter growing season will allow the industry to adapt to climate change in the short to medium term. Extensively grazed animals can be fattened in intensive feedlots during drought years or if seasons become shorter.

Source: The Allen Consulting Group

[19] Commonwealth of Australia 2001, *Australian Agriculture Assessment 2001, National Land and Water Resources Audit*, Volume 2.

INTENSIVE LIVESTOCK INDUSTRY

Vulnerability criterion	Findings
Exposure	The intensive livestock industry in Australia is located close to water and high quality feed stocks. As such, the industry is moderately exposed to the availability of a consistent supply of high quality water for a range of different industries, especially dairy, pigs, poultry, and cattle. The industry is also moderately exposed to the supply of high quality feed stocks, especially in an atmosphere of elevated CO_2 that is likely to result in lower protein content per weight of feed. An increase in the intensity and frequency of extreme events such as drought could increase the cost of production due to higher feed costs and may limit productivity due to feed availability.
Sensitivity	The intensive livestock industry is particularly sensitive to the impacts of climate change due to a number of factors. These include: heat stress, availability of good quality water, susceptibility to pests and diseases, the supply of high quality feed, and the frequency of very hot and humid days. For some industries (dairy) the recovery period will be prolonged after periods of drought and for some individuals the loss of genetic stock and resources may be too great to continue.
Adaptive capacity	In general the intensive livestock industry is well placed to purchase limited supplies of both water and feed. The introduction of environmental management practices such as; the implementation of shading to reduce the impacts of heat stress, the provision of cool water during the hottest days, and the control of pests and diseases ensure that the industry is well placed to adapt to the impacts of climate change. The industry also has the capacity to source feed stocks from those regions that are less affected by the impacts of climate change.
Adverse implications	The intensive livestock industry produces a range of products that represent about $9 billion of export earnings annually. The intensive livestock industry is located in some of the more favourable climatic regions of Australia located close to the supply of high quality feed and water and is therefore less exposed than other industries to the impacts of climate change. A major concern for the industry is the high cost of feed over a prolonged period such as that produced by more frequent droughts.
Potential to benefit	The intensive livestock industries capacity to secure water or make structural improvements (improved shade protection, ventilation in sheds, intensive animal husbandry to monitor pests and diseases) is more substantive than for other industries. Consequently the industry is able to continue to supply product out of season and during period of high demand (drought) to maximize their return on investment. Opportunities exist to consider breeds that are able to tolerate higher temperature and humidity conditions, sourcing feed stocks from non-traditional sources, and better control of climate within animal housing.

Source: The Allen Consulting Group

ANNUAL CROPS (FRUIT AND VEGETABLES)

Vulnerability criterion	Findings
Exposure	Annual fruit and vegetable crops are located across a wide range of environments, but are primarily restricted by access to irrigation water or high annual rainfall, quality soils and topography. The industry is exposed to lower rainfall, increased temperature, increased frequency of droughts, a reduction in frost days and increased frequency of extreme events especially hail and very hot days and summer rainfall. The industry is more exposed in the temperate regions of Australia than in the tropical regions.
Sensitivity	Annual fruit and vegetable crops are particularly sensitive to an increase in diseases and pests following summer rainfall, and are thus highly susceptible to the impacts of climate change where summer rainfall is likely to increase. These crops are also sensitive to extreme events such as hailstorms and drought, although where there is access to irrigated water the impacts of climate change are substantially reduced. The impact of elevated CO_2 on plant growth together with reduced rainfall and increased temperature may provide opportunities in some regions, but is more likely to increase the reliance on nitrogen fertiliser to maintain current production rates.
Adaptive capacity	This industry has a high capacity to adapt to the impacts of climate change and is therefore not nearly as exposed as other sectors. For instance the high returns per hectare obtained from annual fruits and vegetables place them quite favourably to pay for higher water costs than other sectors. The industry is intensively managed and is well placed to handle outbreaks of pests and diseases. The short-term nature of the crop cycles for this industry allows it to be more adaptable to climate change and take advantage of out of season market demands. The industry is generally located close to urban centres and is therefore spread across a range of climatic regions throughout Australia; this provides significant flexibility in managing the risk of failures to meet export and domestic needs.
Adverse implications	Annual fruit and vegetable crops are worth about $2 billion of export and domestic earnings annually. Climate change impacts may have wide reaching affects on the viability of secondary food production that relies on fresh annual fruits and vegetables for domestic and export markets.
Potential to benefit	The intensive nature and high value return from annual fruit and vegetable crops provide this industry with the capacity to secure water or improved shade protection or protection from hailstorms and pests and diseases more than for other sectors. Access to new varieties that are tolerant to drought or have a shorter growing season will allow the industries to adapt to climate change in the short to medium term. This industry has a high capacity to improve water use efficiency through improved soil management and irrigation management. In all cases the potential to benefit is likely to be enhanced where more accurate and reliable annual forecasts are provided, especially in terms of projecting the likelihood of summer rain.

Source: The Allen Consulting Group

PERENNIAL HORTICULTURE (POME, STONE, VITICULTURE)

Vulnerability criterion	Findings
Exposure	The Australian horticulture industry is distributed broadly across a range of environments that have access to irrigated water, generally highly fertile soils and topography. The industry is exposed to the following impacts of climate change: decreased rainfall, increased temperature, increased frequency of drought years, decreased frost days, increased frequency of extreme events, (specially hail and summer rain), and an increase in the number of very hot days. This industry is more exposed in the temperate regions than the tropical regions of Australia.
Sensitivity	The horticultural industry is sensitive to an increase in diseases and pests following summer rainfall, and is thus highly susceptible to the impacts of climate change where summer rainfall is likely to increase. These crops are also sensitive to extreme events such as hailstorms and drought, although where there is access to irrigated water the impacts of climate change are substantially reduced. The impact of elevated CO_2 on plant growth together with reduced rainfall and increased temperature may provide opportunities in some regions, but is more likely to increase the reliance on nitrogen fertiliser to maintain current production rates.
Adaptive capacity	This industry has a high capacity to adapt to the impacts of climate change and is therefore not nearly as exposed as other sectors. For instance the high returns per hectare obtained from perennial fruits place them quite favourably to pay for higher water costs than other sectors. The industry is intensively managed and is well placed to handle outbreaks of pests and diseases. The industry is generally located in regional centres spread across a range of climatic regions throughout Australia; this provides significant flexibility in managing the risk of failures to meet export and domestic needs. However there are some fruits such as pears that are highly exposed to the risk of a reduced number of winter chill days and may not be able to adapt in their current geographical location.
Adverse implications	Perennial horticultural crops are worth about $2 billion of export and domestic earnings annually. Production losses in regional centres are likely to have wide reaching affects on the viability of regional towns. Regional communities and secondary food production in specific regional locations such as the Riverina region of NSW and the Goulburn Valley region in Victoria are highly exposed to the impacts of climate change.
Potential to benefit	The intensive nature and high value return from perennial horticulture provide this industry with the capacity to secure water or improved shade protection or protection from hailstorms and pests and diseases more than for other sectors. Access to new varieties that are tolerant to drought will allow the industries to adapt to climate change in the medium to long-term due to the inflexibility the industry has to change to new varieties. This industry has a high capacity to improve water use efficiency through improved soil management and irrigation management. In all cases the potential to benefit is likely to be enhanced where more accurate and reliable annual forecasts are provided, especially in terms of projecting the likelihood of summer rain.

Source: The Allen Consulting Group

ANNUAL BROADACRE CROPS

Vulnerability criterion	Findings
Exposure	The Australian broadacre cropping industry is located across a wide range of agro ecological zones that differ significantly in their access to rain-fed and irrigated water. Climate change will leave many regions highly exposed due to increased temperature, reduced annual rainfall or reduced water when needed for plant growth. An increase in the intensity and frequency of extreme events such as drought and hail will limit the capacity to grow productive crops in some regions. It is highly likely that the areas currently considered to be marginal in their capacity to produce viable crops will be the most vulnerable to climate change.
Sensitivity	Some regional locations will be more sensitive to the impacts of climate change than others. This sensitivity can be attributed to a number of factors including: heat stress, susceptibility to pests and diseases, seasonal rainfall patterns delivering rain when it is not needed, frequency of frost days and very hot days, number of drought years, and the ability to recover after drought. Some regional communities are highly dependant upon the economic viability of the broadacre cropping sector and are therefore likely to suffer significant decline subject to the impacts of climate change. The impact of elevated CO_2 on plant growth together with reduced rainfall and increased temperature may provide opportunities in some regions, but is more likely to increase the reliance on nitrogen fertiliser to achieve current production rates.
Adaptive capacity	The broadacre cropping industry has few options to adapt to the impacts of climate change and relies very strongly on the ability to obtain a good return in one year out of three. The introduction of drought tolerance into new plant varieties will increase the adaptive capacity of agriculture within a limited range of increased temperature and reduced soil moisture conditions. In addition, improved water use efficiency through better soil management such as no-till, will increase the capacity of the industry to adapt to small changes in climate.
Adverse implications	Broadacre cropping industries remain the lifeblood of regional Australia, with crop production worth about $8 billion of export and domestic earnings annually (principally export). Any adverse impacts of climate change will have a significant detrimental impact on regional communities.
Potential to benefit	The broadacre cropping industry has limited opportunity to adapt to the impacts of climate change with the main adaptations likely to be short to medium term only. Adaptations that will provide on-going productivity in some regions (although the most marginal regions will be the most exposed) are: increased water use efficiency through soil management, increased drought tolerance and shorter season varieties, longer term weather forecasts, a move away from commodity trading and improved protection from pests and diseases. In all cases the potential to benefit is likely to be enhanced where more accurate and reliable annual forecasts are provided, improving the capacity to increase yield and reduce the number of failures in bad years.

Source: The Allen Consulting Group

Forestry

In 2001–02, the value of wood and wood products to the Australian economy was $6.6 billion (1 per cent of GDP). Australia is a net importer of pulp and paper products but exports wood–based panels and woodchips. New South Wales, Victoria, Tasmania and Western Australia contribute to the bulk of this effort. The timber production sector remains a relatively small employer nationwide at 0.86 per cent in direct employment 2000–01. However, for many regional centres forestry can be a major source of income.[20]

There are some 164 million hectares classified as forest, which constitutes 22 per cent of Australia's land area. Of this, about 1 per cent is plantation forests and 7 per cent native forest for timber production.[1] Many of Australia's native forests have international World Heritage significance. Nationally, land clearing exceeds plantation establishment, although plantations are expanding at about 50,000 hectares per year.[21]

Climate change is anticipated to affect forest plantations and native forests through reduction in rainfall in the southern parts of Australia where the bulk of forest production occurs. Severe storm events are likely to increase erosion; temperature increases are likely both to extend the distribution of some pests and diseases and have a negative effect on soil moisture balance. A significant threat to forests, particularly pine plantations, is the projected increasing frequency of bushfires.

Increasing levels of CO_2 in the atmosphere and the warming trend may assist in plant growth where plants are not water limited. For some areas, this may result in increased plantation productivity. However, such gains may be lost with increasing fires, diseases and pests.

Some studies have identified a limited range of long–term average climate for some native species – in the order of 1–2^{o}C. [22] This suggests a poor adaptive capacity for native forests and may require intervention to maintain diversity.

Plantation management has long planning horizons and early attention to the impact of climate change impacts will ensure industry viability. Suggested approaches for adaptation include investigating heat and drought tolerant species and planting regimes to ameliorate climate change impacts. Regional Forest Agreements are an established forward planning mechanism that could be utilised.

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20 Bureau of Rural Sciences (2003), *Australia's State of the Forest Report*, Canberra, p. iv. (Available at **http://www.affa.gov.au**)

21 B. Pittock (ed) 2003, op. cit., p 116-118.

22 IPCC 2001b, op. cit., p 611.

Table 3.2

ASSESSMENT AGAINST FRAMEWORK CRITERIA — FORESTRY

Vulnerability criterion	Findings
Exposure	Reduced rainfall, drought, increased fire hazard, pest infestations and soil erosion could adversely affect forest productivity and the sustainability of native forests. Immature forests are particularly susceptible to drought. Where forests are not water–limited, there may be positive effects from CO_2 fertilisation.
Sensitivity	Sensitivity is moderate for plantation industry. Some native Eucalypt species have a very narrow climate range and may become highly vulnerable.
Adaptive capacity	Plantation forestry has a high adaptive capacity. Native forest has limited adaptive capacity although planning and human intervention could ensure species survival. Planning horizons in this industry are relatively long.
Adverse implications	Forestry contributes about one per cent to GDP and directly employs over 18,600 people.
Potential to benefit	Forestry has the potential to benefit from early attention to adaptation planning through better selection of species and management planning that takes climate change into account.

Source: The Allen Consulting Group

Fishing

The gross value of fisheries production is valued at around $2.3 billion, most of which is exported.[23] In recent years, exports from fisheries have averaged around $2 billion or around 1.5 per cent of Australia's total exports.[24] Around 68 per cent or $1.6 billion of fishing output is attributable to wild catch fishing; the remainder of output comes from aquaculture production, which has been expanding rapidly in recent years.[25]

The Australian wild fishing industry is a high–value, low–tonnage industry. Key outputs include rock lobster, prawns, abalone, tuna and crab.[26] Some of the wild catch species are also successfully farmed — for example tuna — however, nearly all Australian rock lobster, crab and abalone are completely wild caught.[27]

Key fisheries are located off Western Australia, Queensland, South Australia and Tasmania.[28]

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23 ABARE and Fisheries Research and Development Corporation 2004, *Australian Fisheries Statistics 2003,* Canberra p 1.

24 G. Love, D. Langenkamp and D. Galeano 2004, *Seafood outlook to 2008-09,* Australian Commodities, vol 11, no 1., pp 86-98.

25 ABARE and Fisheries Research and Development Corporation 2004, op. cit., p 1.

26 G. Love, D. Langenkamp and D. Galeano 2004, op. cit., pp 86-98.

27 Ibid, p. 88-89.

28 ABARE and Fisheries Research and Development Corporation 2004, op. cit., p 15.

Fishing is heavily climate dependent — particularly wild catch. Research has found that the recruitment and migration patterns of some fish species are sensitive to climatic conditions such as winds, ocean currents and temperature, and rainfall. Species such as Atlantic salmon, Pacific oysters and abalone are known to be highly temperature sensitive. Further, Atlantic salmon in southern Tasmania is currently at the edge of their heat tolerance.[29]

Prospects under climate change

Fishing industries may be exposed to changes in ocean circulation, wave generation, ENSO, cyclones and temperature changes — all of which could impact on ocean productivity. The sector is likely be impacted directly by rising water temperatures, which could reduce the availability of cold–water fish, and changes to other elements of the oceanic ecosystem. A potential decline in plankton and fish larvae could see a reduction in ocean biodiversity — including fish and marine mammals.

Roughly 40 per cent of species of coast, estuarine and continental shelf fish are ‘temperate endemics’, that tend to congregate in specialised habitats. Climate change could be expected to have significant impact on the viability of these endemic species in Australian waters.[30] A recent AGO report on potential climate impacts indicates that ‘a weakening of the Leeuwin Current off Western Australia could jeopardise the $260 million western rock lobster fishery,’[31] which is Australia’s single largest fishery.

Aquaculture can also be sensitive to climate change. According to CSIRO, warmer water temperatures adversely affect salmon productivity and salmon farms can also suffer under drought conditions, because of reduced supplies of the fresh water required for fish health. Other commercially important species, including prawns and barramundi, could be adversely impacted by increasing frequency and intensity of flooding,[32] through increased sedimentation in estuarine and coastal water. Sedimentation can also affect areas of estuarine and coastal habitat, reducing the viability of feeding and breeding areas.[33]

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29 B. Pittock (ed) 2003, op. cit., pp 120-121.

30 B. Pittock (ed) 2003, op. cit., p 118.

31 AGO (2002), op. cit., p 23.

32 According to an IAG report, a 25 per cent increase in 30 minute precipitation will reduce the flooding return period from 100 to 17 years. See Australian Climate Group 2004, op. cit., p 26.

33 AGO 2002, op. cit., p 19.

Table 3.3

ASSESSMENT AGAINST FRAMEWORK CRITERIA — FISHING

Vulnerability criterion	Findings
Exposure	Winds, changing ocean currents, rising sea temperature, run–off from land and estuarine flooding are known to affect a number of fishing industry species. Both wild catch and aquaculture species are affected.
Sensitivity	Sensitivity is known to be high for some species, especially those with specialised habitats and those at the limit of their heat tolerance, such as Atlantic salmon. In other cases sensitivities are difficult to evaluate due to uncertainty about how climate affects life cycles. Overall sensitivity to changes in ocean currents, which would have significant impacts on nutrient availability and recruitment, may be high.
Adaptive capacity	Little information is available on the long–term capacity or rate of adaptation. It seems clear that some species will migrate to more southerly locations as the sea temperature rises although habitat restrictions may limit this migration. Some aquaculture operations operating at the limits of heat tolerance may have limited adaptive capacity.
Adverse implications	Fisheries production has a gross value of about $2.5 billion a year and exports average about $1.6 billion per year (1.5 per cent of total exports). Some industries are at greater risk such as the WA $260 million rock lobster fishery, oyster and abalone farming and Atlantic salmon farming in Tasmania.
Potential to benefit	The potential to benefit from adaptation planning is unclear. The aquaculture industry may benefit from considering climate change as part of longer term planning. Implications for management of wild fisheries require further investigation.
Other issues	The effects of increasing sea temperature and sea level on estuarine fish farming and some species are unknown.

Source: The Allen Consulting Group

Tourism

Output from the Australian tourism industry is estimated to be worth around $32 billion or 4.2 per cent of GDP. The industry accounts for around 5.7 per cent of total employment and 11.2 per cent of total exports.

The tourism industry is heavily reliant on the environment with nature–based tourism or eco–tourism forming a key component of tourism demand within Australia, as well as being a major contributor to export income. Australia's natural eco–systems are a primary factor in attracting overseas tourists, with 40 per cent of all international visitors (and 12 per cent of Australian tourists) visiting national parks or participating in bushwalking.[34]

Table 3.5 depicts the top ten regions in Australia visited by international travellers (excluding capital cities). Seven of the top ten tourist destinations in 1999 were in Queensland and the state accounted for over 60 per cent of international visitors.

34 Department of Industry, Tourism and Resources (n.d.), http://www.industry.gov.au, accessed 5 August 2004.

Table 3.4

TOP 10 REGIONS VISITED BY INTERNATIONAL TRAVELLERS IN 1999

Region	Per cent of total visitors
Gold Coast, QLD	21.4
Tropical North Queensland, QLD	18.4
Petermann, NT	6.2
Alice Springs, NT	5.2
Sunshine Coast, QLD	4.9
Whitsunday Islands, QLD	4.8
Northern Rivers, NSW	4.5
Hervey Bay, QLD	4.3
Northern Queensland, QLD	3.6
Fitzroy, QLD	3.0

Note: Excludes capital cities.
Source: Bureau of Tourism Research (n.d.), *Australian Tourism Data Card:* http://www.btr.gov.au/service/datacard/datacard_action.cfm, accessed 5 August 2004.

The tropical northern and coastal areas of Queensland are particular beneficiaries of tourism. Tourism accounts for around six per cent of the State's output and nine per cent of total employment; both shares are significantly greater than those for Australia as a whole.[35] The central regions of the Northern Territory also feature prominently in the top ten regions visited by international travellers.

Key destinations for nature–based tourism include the Great Barrier Reef (where tourists spend around $776 million per year on visits to the area), the Wet Tropics World Heritage Area in northeast Queensland ($377 million)[36] and Kakadu National Park ($122 million).[37]

Prospects under climate change

Tourism can be expected to face climate change impacts associated with pressures on major ecological sites, and changes in weather patterns affecting the comfort level in tourist areas. For example:

[35] Queensland Tourism 2002, *Fact Sheet — Tourism and the Economy,* Queensland Tourism

[36] K. Higginbottom 2003, *Nature-based tourism; productive or destructive for the environment?,* Wildlife Australia Magazine, Winter 2003, pp 10-13.

[37] S. Driml and M. Common 1995, *Economic and financial benefits of tourism in major protected areas,* Australian Journal of Environmental Management, vol. 2, no. 1. pp 19-29.

- Cairns and the Great Barrier Reef are expected to see multiple dimensions of change. The Reef itself is likely to suffer from coral bleaching events, which have long recovery times and flow on effects for the whole ecosystem. Climate model projections suggest that within 40 years water temperatures could be above the survival limit of corals.[38] Other reef systems, such as Ningaloo Reef in WA, stand to be similarly affected. Changing CO_2 levels and rainfall patterns may adversely affect rainforest biodiversity while increasing severe weather events could damage beaches, tourist facilities and coastal infrastructure. Rising sea levels may also impact on beaches: CSIRO has said that the coastline could possibly retreat horizontally by 50 to 100 times the vertical sea level rise, which could imply a recession of sandy beaches by 4.5 to 88 metres by 2100 under certain climate change projections.[39]

- Shorter snow seasons and reduced mountain snow cover may directly affect ski resorts in the Alpine regions. The AGO's *Living with Climate Change* publication notes that for a warming of 0.3°C with no change in precipitation, the area covered by snow could contract by 18 per cent. A 1.8°C increase in temperatures with eight per cent less precipitation could possibly reduce the snow area by 66 per cent. These represent low and high change scenarios.[40] Some tourism to this region could be lost to New Zealand. A survey conducted by three NSW ski resorts found that if there were 'little natural snow' they would lose 44 per cent of their skiers.[41]

- Rainforests — from Northern Australia to Tasmania — may also be adversely affected by climate change. The Wet Tropics of the Far North are not expected to keep pace with rapid changes in temperature and rainfall; as much as 66 per cent of all endemic vertebrates could be lost in 50 to 100 years depending on the rate and timing of climate variations.[42]

In addition to affecting natural tourist attractions, climate change could impact on the profitability of the industry through increasing temperatures and energy use. Roughly 50 per cent of all energy consumption in hotels is attributable to air–conditioning; rising temperatures may therefore impact on the bottom lines of operators in many areas of Australia.[43]

Although significant effort has been invested in understanding the potential impact of climate change on the commercially–critical natural systems on which Australia's tourism industry has been built, the capacity of this sector to adapt is uncertain, depending on the timing and magnitude of climate change, and impacts and responses at a regional level. The attractiveness of Australia as an international tourist destination will also be affected by impact of climate change here relative to other competing destinations.

Some adaptation options that have been identified include:[44]

- diversification away from reliance on eco–based activities[45];

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38 Australian Climate Group 2004, op. cit., p 27.

39 AGO 2002, op. cit., p 12.

40 AGO 2002, op. cit., p 19.

41 B. Pittock (ed) 2003, op. cit., p 142.

42 Environment Australia 2003, *Wetlands Australia — National Wetlands Update 2003,* Environment Australia: http:www.ea.gov/water/wetlands/publications, accessed 17 September 2004.

43 P. Bohdanowicz and I. M. Martinec 2001, *Thermal Comfort and Energy Savings in the Hotel Industry,* Proc. 15th Conference on Biometeorology and Aerobiology, Kansas City, Missouri, 28 Oct.-1 Nov 2002: American Meteorological Society, Boston, MA, pp 396-400.

44 B. Pittock (ed) 2003, op. cit., p 143.

- industry restructuring; and
- reclamation and preventative investments, including repair of beaches, artificial snow production and hardening of coastal infrastructure and facilities.

Coordination of need and effort can represent a special challenge for this industry. While some players are large with considerable resources and influence over asset management, the majority are small and medium–sized enterprises with limited individual powers to influence outcomes affecting the whole group.

Table 3.5

ASSESSMENT AGAINST FRAMEWORK CRITERIA — TOURISM

Vulnerability criterion	Findings
Exposure	The tourism industry is likely to be affected by increasing sea temperatures and the resultant coral bleaching events, rising sea levels and the impact on beaches and estuaries and increasing adverse weather events such as cyclones causing damage to infrastructure.
Sensitivity	Sensitivity will vary depending on the basis of tourism. Nature–based and eco—tourism activities are key components of the Australian tourism industry and are highly sensitive to climate change. The Great Barrier Reef, beach resorts, Kakadu National Park and Alice Springs are key destinations for international visitors, and these areas are likely to be affected.
Adaptive capacity	Some of the larger tourist operators would have the resources and flexibility to adapt to climate change. However, smaller operators may have limited capacity to diversify away from eco–based tourism. Investment in infrastructure, such as securing beaches, making artificial snow, and diversifying activity bases could assist.
Adverse implications	The tourism industry is worth about $32 billion (4.2% of GDP) and employs almost 10% of the workforce (directly and indirectly). Environmental assets drive a significant component of this income. The impact on the key environments is likely to have significant adverse implications for employment and revenue especially for Queensland.
Potential to benefit	Some industries have already invested in marketing strategies and preventive investments, for example, the skiing industry has invested in snowmaking machines and alternative recreation pursuits in the environment (walking, bike–riding, tennis).

Source: The Allen Consulting Group

[45] As noted by Pittock (see B. Pittock (ed) 2003, op. cit., p 100), expanding recreational industries can sometimes increase the stress on elements within the ecosystem and require careful assessment.

3.2 Climate pressures on the natural environment

Climatic conditions strongly influence the availability and quality of Australia's natural resources such as water and arable land. The supply of water is dependent upon rainfall patterns — both levels and timing. The availability of arable land, critical to crops and grazing, is dependent on rainfall, water table levels and winds, which can cause soil erosion. Climate also impacts on the frequency and extent of drought and bushfires — the occurrence of which have significant implications for our natural resources and the wider economy. The challenge of resource management in some areas is likely to be amplified through trend and variability pressures associated with climate change.

Water

Water has frequently been an issue in Australia, because of its scarcity and the high degree of inter–annual and inter–decadal variability in rainfall levels. Australia is a dry continent and water scarcity is amplified by high evaporation rates.[46] Annual rainfall variability in Australia is greater than that for any other continental region[47] and run–off and stream flow, critical factors affecting the capacity of dams, vary to an even greater extent.[48] Changes to water availability are likely to affect many other sectors and elements of the natural environment. It is also likely to affect economic and social aspects for regions and cities.

Mean annual rainfall in Australia also varies substantially across the continent. Large areas of the continent, predominantly coastal, have a mean annual rainfall between 600 and 1,500 millimetres per year, which is comparable with most of Europe and North America.[49] However, approximately 30 per cent of the continent is either arid or semi–arid, receiving less than 200 millimetres of rainfall per year.[50]

Water is a fundamental input to many systems within Australia. Constraints associated with the availability of water affect both urban and rural activities, most notably the supply of water for productive and environmental purposes in rural Australia and the supply of water for households and industrial purposes in cities. Water availability stands to be significantly affected by climate change — with the potential for even small changes to tip the balance for some systems and regions.

Water use

Water consumption in Australia is dominated by the agricultural industry. The sector accounts for close to 67 per cent of the nation's total water use (Table 3.7). Australia uses a greater proportion of its water for irrigation and other rural purposes than any other developed country.[51] The gross value of irrigated agricultural production is valued at around $9.6 billion; roughly 28 per cent of total agricultural output.[52]

46 A. Henderson-Sellers and R. Blong 1989, *The Greenhouse Effect Living in Warmer Australia,* NSW University Press: Sydney, p 125.

47 ABS 2004b, *Water Account Australia, 2000-01,* cat. no. 4610.0. AusInfo: Canberra, p 2.

48 A. Henderson-Sellers and R. Blong 1989, op. cit., p 125.

49 ABS 2004b, op. cit., p 2.

50 D. Stehlik, I. Gray and G. Lawrence 1999, *Drought in the 1990s; Australian Farm Families Experiences,* Rural Social and Economic Research Centre, Queensland and Centre for Rural Social Research, NSW.

51 A. Henderson-Sellers and R. Blong 1989, op. cit., p 125.

52 ABS 2004b, op. cit., p 55.

Crops such as cotton, rice and sugar are extensively irrigated and dairy farming is also a relatively water intensive industry.[53] However, the key component of agricultural water consumption is pasture production — it is estimated that nearly half of Australia's irrigated water is used for this purpose — mainly in the Murray Darling Basin.[54]

Table 3.6

WATER CONSUMPTION IN AUSTRALIA, 2000–01

Sector	Water use (ML)	Per cent of total use
Agriculture	16,660,381	66.9
Forestry and Fishing	26,924	0.1
Mining	400,622	1.6
Manufacturing	866,061	3.5
Electricity and Gas Supply	1,687,778	6.8
Water Supply	1,793,953	7.2
Households	2,181,447	8.8
Other	1,291,493	5.2
Total	**24,908,659**	**100.0**

Source: ABS 2004b, *Water Account, 2000–01*, cat. no. 4610.0, AusInfo, Canberra.

Water supply

Every major mainland city faces water stress already. In many cases climate change will increase these pressures through increased temperature and possibly lower rainfall combined with more frequent ENSO events. Dams could be susceptible to extreme rainfall events if these exceed historical design standards. Dam overtopping and failure can have catastrophic short and medium term effects in terms of human and economic losses.

Adelaide and Perth typically receive relatively low rainfall while at the same time experiencing high rates of evaporation. Dry conditions in both cities in recent years have prompted the implementation of a range of water restrictions to try and curb the consumption of water.[55] Both cities are considered vulnerable to future water supply problems.[56] Current projections indicate that in as little as ten years, the demand for water in Adelaide will exceed available supply during dry periods.[57] Water supply concerns in Perth have recently prompted the State Government to announce plans to construct a desalination plant to supplement the city's existing water supply system (see Box 3.4).

53 ABS 2004b, op. cit., p 17.

54 A. Henderson-Sellers and R. Blong 1989, op. cit., p 126.

55 Cumulative shortfalls in inflow and city water storages in other Australian capitals have also led to water restrictions being introduced in Melbourne, Sydney and Canberra in recent years, see B. Pittock (ed) 2003, op. cit., p 87 for more details.

56 B. Pittock (ed) 2003, op. cit., p 87.

57 Water Proofing Adelaide - Government of South Australia 2004, *Water Proofing Australia; Exploring the Issues — A discussion paper,* Government of South Australia: Adelaide, p 6.

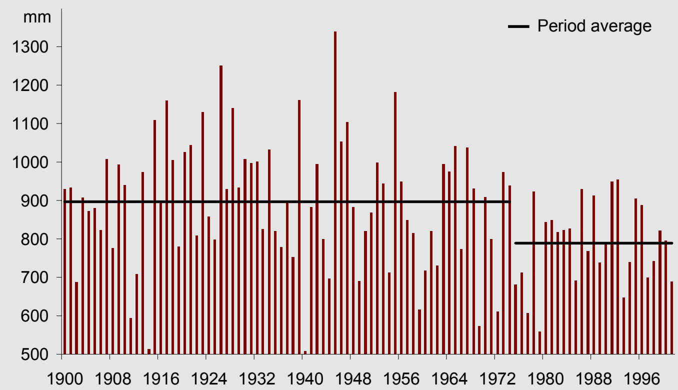
Water scarcity and reform agendas

In many instances the demand for water from our river systems has exceeded sustainable levels of supply and this has led to the emergence of environmental concerns and water scarcity. An area of prime concern in this regard is the Murray–Darling Basin where extraction for irrigation has led to 80 per cent of the median river flow being diverted for consumptive uses. The lower Murray River currently experiences drought conditions one year out of two.

Box 3.2

RAINFALL IN SOUTHWEST WESTERN AUSTRALIA

Annual rainfall in the southwest of Western Australia has declined by around ten per cent since the mid 1970s. Over this time there has been a marked shift toward drier winter conditions and researchers attribute at least some of this shift to global warming. The chart below depicts annual rainfall in the southwest of Western Australia since 1900 with average rainfall for the periods 1900 to 1975 and 1975 to 2002 illustrated by the black line.



In response to growing concerns over Perth's water supply, the Western Australian Government recently announced plans to build a $350 million desalination plant in Kwinana in the state's southwest. Typically, the main impediment to the use of desalination for water supply has been its high cost, though technological advances have made the technology more affordable over the past decade or so.

The plant, to be built and owned by the Water Corporation, will provide an additional 45 gigalitres of water to Perth's water network, equivalent to around 17 per cent of current supply.

The desalination plant will provide a source of water that is independent of climatic conditions and is a direct response to decreasing rainfall in the southwest of the state in recent years.

The plant will be able to produce water at a cost of around $1.11 per kilolitre, nearly double the current costs of delivering water to urban areas. Additional costs will be passed on to consumers through increased charges.

Sources: ABC Western Australia (n.d.), http://www.abc.net.au/wa/stories/s1164601.htm, accessed 15 September 2004; Bureau of Meteorology; Indian Ocean Climate Initiative, www.ioci.org.au; The Hon. Geoff Gallop 2004, *Desalination plant to become a vital source for State's water supply*, media release, 29 July 2004; and Water Corporation, www.watercorporation.com.au.

Based on current projections it is expected that within 20 years, reduced flows and increased salinity in the Murray–Darling Basin will result in Adelaide's main water supply failing World Health Organisation Standards two days in five.[58] However, water supply issues are not constrained to Adelaide and affect most sizeable population centres. Given current projections of growth in our major cities, water planners believe that a 25 per cent reduction in per capita water use is required to maintain adequate supply to cities over coming decades.[59] Climate change could well impact on this timeline and put further pressure on an already stretched resource.

In response to growing concerns over the sustainability of water supply, COAG agreed to implement the National Water Initiative in 2003. The initiative, outlined in Box 3.3, built upon previous COAG work on water reform. Climate change is likely to have major impact on this agenda, and give major impetus to many of its elements.

Box 3.3

THE NATIONAL WATER INITIATIVE

In 2003, COAG agreed that there was a need to re–design its water reform agenda to increase the productivity and efficiency of water use, sustain rural and urban communities and to ensure the health of river and groundwater systems. In response COAG developed the National Water Initiative with the following aims:

- to improve the security of water access entitlements by establishing the risks of reductions in future water availability and by returning over–allocated systems to sustainable allocation levels;
- to ensure ecosystem health by implementing regimes to protect environmental assets;
- to ensure water is put to best use by encouraging the expansion of water markets and trading across districts and States; and
- to encourage water conservation in cities, including better use of stormwater and recycled water.

Also announced at the time of the National Water Initiative was an Intergovernmental Agreement between the Australian Government and the governments of New South Wales, Victoria, South Australia and the Australian Capital Territory to establish arrangements for investing $500 million over five years to address water over–allocation in the Murray–Darling Basin.

Source: National Water Initiative (n.d.), *National Water Initiative, Discussion Page* : http://www.pmc.gov.au/docs/national_water_initiative_progress.cfm, accessed 14 September 2004.

Prospects under climate change

Climate change is likely to significantly affect rainfall patterns in Australia, and its influence may already be evident in some areas. Climate science points to the prospect of drier conditions in the southern part of Australia — with some significant regional impacts — and wetter conditions in the north. Variations in rainfall conditions are also important, with greater intensity of rainfall events predicted by the modelling, adding to flooding risk even when season rainfall totals are fairly stable.[60]

[58] Wentworth Group The 2002, *Blueprint for a Living Continent: A Way Forward From The Wentworth Group of Concerned Scientists,* Wentworth Group: Sydney, 1-Nov-02.

[59] Wentworth Group, The 2003, *Blueprint for a National Water Plan,* Wentworth Group: Sydney, 31-Jul-03.

[60] B. Pittock (ed) 2003, op. cit., pp 62-64.

Changes in water availability can obviously have a profound effect on a wide range of human and natural systems. Scarcity will make water even more valuable, and changes in the geographic distribution of supply can impact on costs and revenue flows in a water trading environment. Box 3.4 illustrates some recent analysis of diminished water availability scenarios for the irrigation industry. However, given the ubiquitous nature of water use, reduced availability can add to costs and drive the search for greater efficiency and alternative supply across the economy.

Box 3.4

COSTS TO ECONOMY OF REDUCTIONS IN IRRIGATION ALLOCATIONS

In a report examining the implications for water reforms in the national economy, the Centre for International Economics examined the costs of water scarcity via direct reductions in existing irrigation allocations Australia–wide. Irrigation allocations were reduced by 5, 10, 15 and 20 per cent from base case projections starting in 1996–97. The cost of the irrigation reductions to the Australian economy in 2009–10 were estimated as follows:

- a 5 per cent reduction in Australian irrigation allocations (720 GL) resulted in GDP losses of $136 million;
- a 10 per cent reduction in Australian irrigation allocations (1,440 GL) resulted in GDP losses of $324 million;
- a 15 per cent reduction in Australian irrigation allocations (2,160 GL) resulted in GDP losses of $508 million; and
- a 20 per cent reduction in Australian irrigation allocations (2,890 GL) resulted in GDP losses of $751 million.

Source: Centre for International Economics 2004, *Implications for Water Reforms for the National Economy*, prepared for the National Program for Sustainable Irrigation, Canberra.

Table 3.7

ASSESSMENT AGAINST FRAMEWORK CRITERIA — WATER

Vulnerability criterion	Findings
Exposure	Overall decreased precipitation in the populated regions and increasing temperatures are likely to markedly affect water resources in terms of quantity and quality. Increasing incidence of floods and drought will also impact on sustainability of the water supply.
Sensitivity	Sensitivity is very high. Many sectors and other natural resources are dependent on water availability. Most major cities and many regional towns are already experiencing water shortages. Water use for irrigated agriculture accounts for approximately 67% of total water consumption. Dams could be susceptible to extreme rainfall events. The ecological values of aquatic ecosystems depend on adequate environmental flows.
Adaptive capacity	Water restrictions have been implemented in many urban centres and infrastructure changes such as desalination plants, dams, storm–water use and recycled water are under consideration. The National Water Initiative is a key initiative to progress water reform policy and adaptation options. Competing demands for water resources come from agricultural irrigation, urban settlement needs and ecosystem needs.
Adverse implications	Irrigated agricultural products account for about 28% of agricultural output ($9.6 billion). Water allocations may need to be restricted.
Potential to benefit	Action is already underway to plan for future water needs in a dry climate with an imperative to improve efficiency of water use. The impact of climate changes needs to be factored into this existing effort.

Source: The Allen Consulting Group

Salinity

Approximately 2.5 million hectares of Australia's land is currently affected by dryland salinity. Most of the land affected was once productive agricultural land — estimates place the proportion of agricultural land affected by salinity at around 4.5 per cent.[61] Predictions made as part of the *Australian Dryland Salinity Assessment 2000* suggest that unless effective solutions are implemented, the area defined as having high potential for developing dryland salinity could increase threefold to 17 million hectares by 2050.[62] Changes in precipitation and agricultural practices, together with sea level and the mix of plant species can affect salinity trends and outcomes.

Salinity affects most states and territories in Australia. Figure 3.7 depicts the areas identified as having a high risk of developing salinity. The high risk areas are located along the southern regions of the continent, primarily in key agricultural regions of Western Australia, South Australia and Victoria.

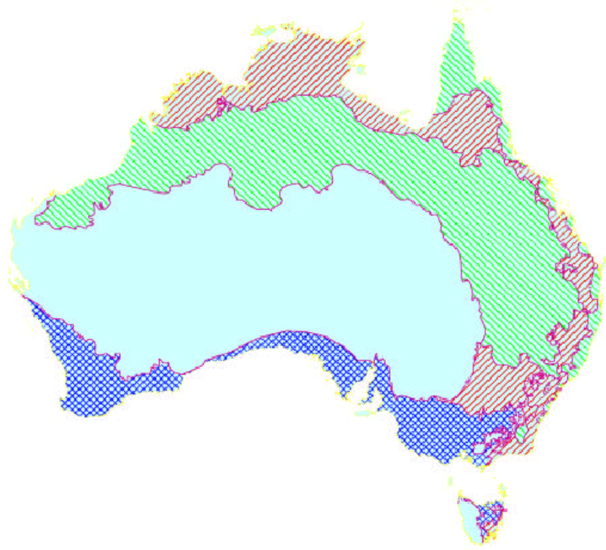
Areas of moderate risk are prominent throughout much of New South Wales and Queensland. The northern regions of the Northern Territory are also classed as moderate risk areas.

61 Prime Minister's Science, Engineering and Innovation Council (PMSEIC) 1999, *Moving Forward in Natural Resource Management: The Contribution that Science, Engineering and Innovation can Make,* Canberra.

62 National Land and Water Resources Audit 2001, *Australian Dryland Salinity Assessment. Extent, Impacts, Processes, Monitoring and Management Options,* Canberra.

Figure 3.7

RISK OF DRYLAND SALINITY IN AUSTRALIA



Legend: Light blue—no risk; Light green—low risk; Red—moderate risk; Dark blue—high risk.
Source: Prime Minister's Science, Engineering and Innovation Council 1999, op. cit., p 6.

While salinity has traditionally been seen as an agricultural problem, it is now appreciated that the non–agricultural costs of salinity are also significant. Table 3.8 depicts some of the agricultural and non–agricultural costs of salinity.

Table 3.8

THE COSTS OF SALINITY

Type of Cost	Agricultural Costs	Non–agricultural Costs
Preventative action	Costs of establishing preventative treatments: areas of perennial plants, surface drainage.	Costs of engineering works (pumps, drains, evaporation basins) and revegetation to protect buildings, roads, bridges and other infrastructure.
Replacement, repairs and maintenance	Repairs to buildings, replacement of dams, establishment of deep drains to lower saline groundwater.	Repairs to houses and other buildings, desalination of water resources, repairs to infrastructure, restoration of natural environments.
Direct losses	Reduced agricultural production, reduced flexibility of farm management.	Extinctions, loss of biodiversity, loss of amenity, loss of aesthetic values, loss of water resources, eutrophication of waterways, loss of development opportunities on flood plains.

Source: Department of Treasury and Finance WA 2001, *Economic Tools to Tackle Dryland Salinity in Western Australia, Economic Research Paper,* Perth: Department of Treasury and Finance WA, October, p 8.

It is estimated that around $130 million is lost annually as a direct result of restrictions on agricultural production — including crops, meats and wool — due to salinity–affected land. This estimate does not include costs incurred by farmers arising from the need to protect land and surface waters from salinisation nor does it consider costs associated with the adoption of more sustainable agricultural practices.[63]

The existence of shallow, saline groundwater damages public infrastructure such as roads, bridges, and communication and gas pipelines. In south western New South Wales, for example, it is estimated that 34 per cent of state–owned roads and 21 per cent of national highways are affected by high water tables. Saline water and high water tables also impact on urban households by causing structural damage to houses, and damage to hot water systems and household appliances. In total, it is estimated that the costs arising from repairing, replacing and protecting vulnerable infrastructure is in the order of $100 million per year.[64]

Rainfall, streamflow and other climate–related factors have a significant effect on patterns of salinity. Commissioning an assessment of how climate change is likely to affect salinity in Australia might therefore be a useful priority for the National Action Plan for Salinity.

Drought

Droughts can have widespread economic impacts — mainly exhibited through their affect on agricultural output. Natural pastures and vegetation have evolved to become highly resistant to periods of low rainfall whereas cereal crops such as wheat are far more sensitive to water limitations.[65] Reduced crop yields, diminished harvests, stock losses and soil erosion are some of the impacts that drought has on the farming sector.[66]

Reduced farm incomes adversely affect the economies of small country towns — with farm expenditure representing at least one third of most small rural town economies,[67] while severe droughts, such as the 2002–03 drought, impact noticeably on the economy as a whole (Box 3.5).

Box 3.5

THE COSTS OF AUSTRALIA'S RECENT DROUGHT

Over much of 2002–03, drought affected significant areas of rural Australia. Around 90 per cent of New South Wales, 65 per cent of Queensland and much of Victoria was officially drought–declared by late 2003. Below average rainfall was also recorded in parts of South Australia, Tasmania, Western Australia and the Northern Territory.

The extensiveness of the drought was felt in all agricultural sectors, but particularly those associated with broad acre cropping. The 2002–03 cropping season was one of the worst on record; production fell by around 27 million tonnes, or 60 per cent, relative to 2001–02.

At just under 18 million tonnes, total cropping production in 2002–03 was at its lowest level since the drought of 1982–83. Output of wheat and barley fell by over 50 per cent, and fruit and vegetable production also declined significantly relative to 2001–02 levels. The livestock sector was also adversely affected; sheep and lamb numbers were at their

[63] PMSEIC 1998, *Dryland Salinity and its Impacts on Rural Industries and the Landscape*, Canberra, p 5.

[64] Ibid, p 6.

[65] ABS 1998, *Drought in Australia*, available at http://www.abs.gov.au/Ausstats/abs@.nsf/0/068F13BCCD03F27BCA2569DE001F1072?Open, accessed 26 August 2004.

[66] A. Henderson-Sellers and R. Blong 1989, op. cit., p 114.

[67] ABARE 2000, *Impact of Farmer's Expenditure on Employment and Population in Australian Towns*, Current Issues, 2000.4, Canberra.

lowest level in over 50 years and cattle numbers also declined during the year.

The economic consequences of the drought were severe. Farm gross domestic product fell by almost a quarter in 2002–03 ($3 billion) and rural exports fell by around 27 per cent. The drought has been estimated to have subtracted about one per cent from Australia's GDP in 2002–03; equal to around $6.6 billion.

Sources: ABARE 2004a, *Farm Survey Results, March,* Australian Bureau of Agricultural and Resource Economics: Canberra; ABARE 2003a, *2002–03 drought review of its impact on Australian agriculture,* Australian Commodities, vol. 10, no. 3; E. Bennett 2004, *Assistance is no dry argument*, Australian Financial Review, 29 July 2004, Special Report, p 7; Department of the Treasury (n.d.), *The Impact of the 2002–03 Drought on the Economy and Agricultural Employment,* Department of the Treasury: http://www.treasury.gov.au/documents/817/HTML/docshell.asp?URL=03_article_2.asp, accessed 26 July 2004, p 1; and Reserve Bank of Australia 2002, *Economic Effects of the Drought in Statement on Monetary Policy*, Nov–02, Reserve Bank of Australia: Sydney.

Biodiversity

Over many thousands of years of isolation from the rest of the world, Australia's ecosystems have evolved to cope with its unique climatic conditions. There are an estimated 500,000 different flora and fauna species across Australia, of which around 80 per cent are unique to the country.[68] Australia is home to 16 World Heritage Areas, many of which have strong natural heritage values, ranging from tropical rainforest areas in Queensland's north, the Kakadu wetlands and Great Barrier Reef to Tasmanian wilderness areas.[69]

Australia also has more endangered species than any other continent. The National List of Threatened Flora lists 61 species that are already extinct and a further 562 species that are either endangered or critically endangered. For fauna, 54 species are extinct and a further 127 are classed as endangered or critically endangered.[70] Climate change can have a profound impact on species in the coming years.

Prospects under climate change

Many of Australia's rich and diverse ecosystems are highly sensitive to climate change and likely to have difficulty adapting to potentially rapid variations in climate patterns and trends. A range of potential biodiversity threats can be attributed to climate change. These include:

- Pressure on native forests and woodland habitats
  - Increasing temperatures and drier conditions can adversely affect Eucalypts, Dryandra and Acacia shrubs. They can also threaten some sensitive animal species. For example, in southwest Australia, CSIRO modelling shows that the habitats for all frog and many mammal species would be significantly reduced with only a 0.5°C warming.
  - Initial work in North Queensland has projected that a 1°C increase in temperature could significantly reduce — possibly by up to 50 per cent — the upland tropical rainforests of the World Heritage–listed Wet Tropics of Queensland. This rainforest loss could see a reduction in the number of rainforest vertebrate species of almost 40 per cent.
- Pressure on coastal environments and wetlands

68 PMSEIC 2002, *Sustaining our Natural Systems and Biodiversity:* Canberra, pp 1-7.

69 Department of Environment and Heritage, www.deh.gov.au.

70 For more information see St Pius X College web site: http://www.spx.nsw.edu.au/src/Links/endanganim.html, accessed 20 September 2004.

– Sea level rises and changes in rainfall patterns and salinity can affect sensitive wetland environments. Significant areas in Kakadu and the Macquarie Marshes are considered to be under threat — but our understanding of potential climate impacts on our heritage listed and Ramsar wetlands is far from comprehensive.

- Coral bleaching

  – Coral reefs are highly sensitive to water temperature changes. An increase of 1°C to 2°C in sea temperature might cause significant distress to corals, which have evolved in a narrow temperature band. Projections from global climate models indicate that sea temperatures could rise beyond the survival limit of corals in 40 years time. This could have flow on effects for the marine species that currently live in the reefs.

  – In 1998, a significant coral bleaching event occurred globally which damaged 16 per cent of the world's reefs and 3 per cent of Australian reefs. Climate change threatens to add to existing pressures from sediment and nutrient run–off from agriculture, as well as commercial and recreational fishing.[71]

- Pressure on alpine habitats and species

  – Increasing temperatures could shorten the snow season and impact on a number of species that rely on snow cover for their survival, including the Mountain Pygmy Possum. The AGO's *Living with Climate Change* publication noted that a warming of only 0.3°C, holding precipitation constant, would result in an 18 per cent contraction in snow cover.[72]

- Spread of weeds and pests

  – The spread of some weeds in Australia has been found to be heavily dependent upon climatic conditions — the Prickly Acacia and the Rubber or Woody Vine, both recognised as posing a threat at a national level, have been found to favour higher temperatures.[73]

  – The cane toad is also predominantly found in areas of high temperature and humidity.[74]

It is important to note that some existing species may be advantaged by climate change. However *a priori* one would expect a reduction in biodiversity due to the large number of species adapted to 'narrow' climate or topography niches. Current studies appear to have only 'scratched the surface' in building our knowledge of the climate dependency of important Australian species and how these are likely to respond to variations in climate conditions.

[71] Australian State of the Environment Committee 2001, *Australia State of the Environment 2001,* Australian State of the Environment Committee: Canberra, p 34.

[72] AGO 2002, op. cit., p 19.

[73] D. Kriticos, R. Sutherst, J. Brown, S. Adkins and G. Maywald 2003, *Climate change and the potential distribution of an invasive alien plant: Acacia nilotica ssp. Indica in Australia*, Journal of Applied Ecology, vol. 40, pp 111-124; and D. Kriticos, R. Sutherst, J. Brown, S. Adkins and G. Maywald 2003a, *Climate change and biotic invasions: a case history of a tropical woody vine,* Biological Invasions, vol. 5, pp 145-165.

[74] Queensland Environmental Protection Agency, http://www.epa.qld.gov.au/nature_conservation/wildlife/feral_animals/cane_toad/ , accessed 14 September 2004.

However, options for adaptation by natural systems — to match the events and time scale dictated by climate change — are expected to be limited. Plants and animals confronted by a changing environment tend to be replaced by better suited species as an outcome of natural selection, rather than re–invent themselves and their behaviours on a decadal timescale. There is scope for species migration, but species in isolated and unique habitats could come under intense pressure from climate change.[75]

There is a clear need for human intervention to facilitate the adaptation of response of natural systems — which have no inherent capacity to anticipate and plan for growing climate pressures — over the coming years. Work is currently under way in this area under the auspices of the National Biodiversity and Climate Change Action Plan (http://www.deh.gov.au/biodiversity/publications/nbccap/index.html).

Table 3.9

ASSESSMENT AGAINST FRAMEWORK CRITERIA — BIODIVERSITY

Vulnerability criterion	Findings
Exposure	Increasing temperatures and decreased rainfall in Southern Australia and the increase in sea temperatures will impact differentially on flora and fauna. The spread of pests and diseases and changed fire regimes will also expose biota to additional stress.
Sensitivity	Many ecosystems are highly sensitive to climate change especially coral reefs, alpine regions, wetlands and the wet tropics in Queensland. Species most at risk are those at the edge of their temperature limit, or in very specialised habitats. World Heritage listed systems have special importance.
Adaptive capacity	For many species the adaptive capacity is low especially those in isolated or unique habitats. Action to reduce additional stress on ecosystems (e.g reduce weed infestation) is feasible. The National Biodiversity and Climate Change Action Plan has identified seven key action areas for improving adaptive capacity.
Adverse implications	Loss of biodiversity is likely to increase especially with rapid climate change. Australia is one of the twelve most biologically diverse nations in the world. Eighty per cent of flora and fauna are unique to Australia.
Potential to benefit	Potential to benefit from planned adaptation varies. There is considerable scope to increase the resilience of many systems by relieving other stresses. A National Climate Change and Biodiversity Action Plan has been agreed by all jurisdictions. Some species may be advantaged while others decline.

Source: The Allen Consulting Group

Bushfire

The geographic location and the topography of Australia mean that almost all vegetation types in the country are fire prone. Only the tropical rainforests of north Queensland can be said to be relatively fire free.[76]

75 B. Pittock (ed) 2003, op. cit., pp 100-101.

76 ABS 1995, *Drought in Australia,* Australian Bureau of Statistics: http://www.abs.gov.au/Ausstats/abs@.nsf/0/6C98BB75496A5AD1CA2569DE00267E48?Open, accessed 26 August 2004.

The most severe fire weather occurs in the south eastern corner of Australia. Climatic conditions in these areas produce strong dry winds, particularly during summer, that are conducive to the rapid spread of fire once it has commenced. The south eastern areas of Australia and Tasmania along with the southwest corner of Western Australia are also home to tall timber forests that provide heavy fuel loads for fires. It follows that the greatest potential for bushfire disaster is where people have built in close proximity to the tall, wet forests of southern Australia, specifically in Victoria, southwest Western Australia and southern Tasmania.[77]

Over the period spanning 1967 to 1999, the occurrence of significant bushfires — 23 in all — cost the Australian economy around $2.5 billion. Bushfires tend to occur in cycles following prolonged dry spells, as was the case in 2002–03 when fires burned across the nation following the severe drought[78] (see Box 3.6).

Box 3.6

AUSTRALIA'S 2002–03 FIRE SEASON

The 2002–03 fire season was one of the most serious on record with over three million hectares of bushland and vegetation destroyed across the country.

In the months preceding the bushfires, severe drought, below normal humidity and high daytime temperatures combined to create an environment that was highly susceptible to the spread of bushfires.

In January 2003, lightning strikes from a severe storm sparked 87 fires in the drought–affected area of north east Victoria, and 60 fires in southern NSW and the adjoining areas of the ACT. Over coming weeks the fires spread rapidly, eventually merging into one continuous line spanning an area of 1.7 million hectares.

Western Australia and Tasmania also experienced significant losses due to the spread of bushfires at around the same time. A summary of the damage incurred is given below.

- In Victoria the bushfires resulted in 400 injuries, 36 lost homes, over 1,324,000 hectares of burnt land and the loss of 2,800 sheep, 850 cattle and equipment.
- The NSW fires took three lives, approximately 86 residential homes and burnt 1,465,000 hectares of land. Around 3,400 stock were lost including horses, cattle and sheep.
- The fires that reached suburban Canberra resulted in four deaths, numerous injuries, the loss of 501 houses, damage to over 160,000 hectares of burnt land (almost 70 per cent of the ACT) and major loss of government infrastructure and facilities. The fires resulted in an estimated insurance loss of $350 million.
- WA experienced its worst fire season since 1960–61 in terms of area burnt.
- Tasmania experienced 1,500 vegetation fires that burnt a total of 52,000 hectares of land. Six homes were lost along with numerous pine plantations and several hundred farm animals.

Sources: House of Representatives Select Committee into the Recent Australian Bushfires 2003, *A Nation Charred: Report on the inquiry into bushfires,* House of Representatives Select Committee into the Recent Australian Bushfires: Commonwealth of Australia: Canberra.; and T. Coleman 2002, *Insurance and Climate Change: An Australian Perspective,* Insurance Australia Group, Sydney

[77] ABS 1995, op. cit.

[78] Bureau of Transport Economics 2001, *Economic Costs of Natural Disasters in Australia,* Bureau of Transport Economics: Canberra.

The incidence of bushfire is likely to be impacted by the temperature, humidity and precipitation changes brought about by climate change. According to a recent US climate change study, a 1°C mean summer temperature increase could result in an increase in the frequency of fires within a range of 17–28 per cent. [79] The intensity of fires will also be affected by climate conditions (that can affect the availability of fuel in the form of scrubby undergrowth) and the frequency of fire events (which affect the build up of undergrowth and leaf litter).

Storms, floods and cyclone damage

Over the period 1967 to 1999, the average annual cost of weather related disasters was around $942 million per year. One third of these losses were attributable to floods, 30 per cent from severe storms and 28 per cent from cyclones.[80]

The insurance industry bears a large portion of the costs of weather–related disasters; insurance costs over the period averaged around $290 million per year.[81] Severe storms that have tracked over densely populated areas make up a disproportionate amount of the overall storm claims. The Sydney hailstorm that occurred in 1999 accounted for over one quarter of IAG's total weather related claims over a 15–year period (see Box 3.7).

Box 3.7

THE SYDNEY HAILSTORM

The Sydney hailstorm of April 1999 is responsible for the largest insured loss from a single event in Australian insurance history. In present day values, the estimated insurance loss from the storm is around $1.7 billion, the only event to come close to this in terms of insured losses is the Newcastle earthquake of 1989 which has an estimated loss of $1.1 billion. Total economic costs of the storm are estimated to be around $2.2 billion.

The hailstorm occurred within a thunderstorm which formed to the south of Sydney and affected almost all the entire eastern seaboard suburbs of Sydney. It has been estimated that the amount of hail that fell on Sydney during the storm was in the order of 500 000 tonnes; much of it being the size of tennis balls. The thunderstorm was accompanied by strong winds and rain which also contributed to the storm's damage.

In total, there were over 111 000 insurance claims made in relation to the hailstorm, the majority of which were motor vehicle related claims resulting from hail damage. Residential building and content claims also formed a significant part of total claims. In addition, the storm caused business interruptions and extensive damage to aviation and marine craft. The event resulted in one loss of life with a further 100 people sustaining injuries.

Despite widespread damage, business interruptions and general inconvenience, industry analysts identified some positive economic effects arising from the storm. Industry sectors that were identified as potentially gaining from the event include loss adjusters, building contractors, the motor industry and building material suppliers.

Sources: ACCC 2002, *Insurance Industry Market Pricing Review*, available at http://www.accc.gov.au/content/index.phtml/itemId/321637; M. Steingold and G. Walker 1999, AON Re *Sydney Hailstorm 14 April 1999: Impact on Insurance and Reinsurance*. http://www.aon.com.au/pdf/reinsurance/Aon_Sydney_Hailstorm.pdf; BTRE 2001, *Economic Costs of Natural Disasters in Australia*; http://www.btre.gov.au/docs/reports/r103/r103.aspx; T. Coleman 2002, *The Impact of Climate Change on Insurance Against Catastrophes.*: Insurance Australia Group Working Paper.; Insurance Council of Australia (IAG) 2003, *Submission to the House Committee into Recent Bushfires.*; and Insurance Disaster Response Organisation (IDRO), www.idro.com.au, accessed 28 July 2004.

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79 E. Mills, E. Lecomte and A. Peara 2001, *US Insurance Industry Perspectives on Climate Change,* US Department of Energy: University of California: Berkeley.

80 Bureau of Transport and Regional Economics 2004, *Risk in Cost Benefit Analysis: Implications for Practitioner,*. Working Paper 61, Bureau of Transport and Regional Economics: Canberra p 35.

81 Ibid, p 24.

Given that a disproportionately large share of insurance industry losses come from extreme weather events, changes in the nature and frequency of these events could appreciably alter the price and availability of insurance. For the insurance industry itself, the task of managing risk becomes increasingly difficult if past weather patterns are rendered poor predictors of future weather patterns due to climate change.[82] There is growing anxiety within insurance markets about the implications of climate change for that industry, given that climate science suggests an increase in both the frequency and severity of storm activity as the Earth's climate systems become more energetic see Box 3.8).[83]

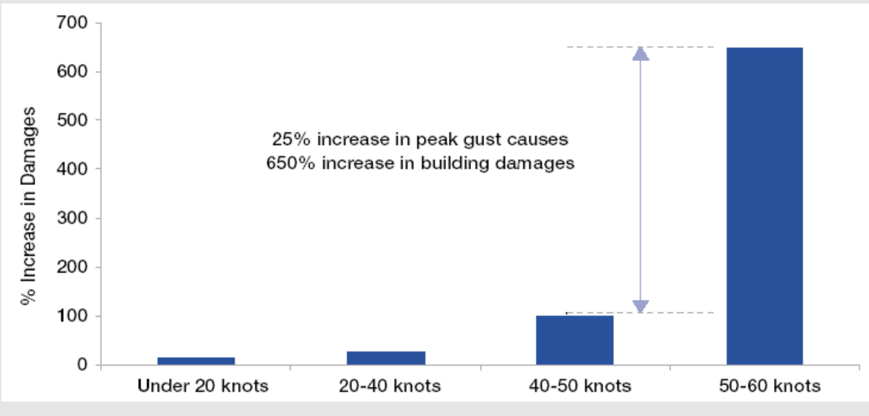
An Australian trend toward coastal living also means that the community's exposure to extreme climatic events such as tropical cyclones and storm surges will continue to increase.[84] A similar trend in the United States has been identified as a crucial factor behind the trend of increasing in storm damage costs observed since 1960.[85] The prospect of increases in extreme events also highlights the human costs, and the need to factor climate change issues into coastal land use planning and natural disaster planning. The COAG work on reviewing natural disasters in Australia is an important step in working towards adaptation.[86]

Box 3.8

ESCALATION IN DAMAGE FROM STRONGER STORM EVENTS

Small increases in storm severity can result in large increases in damage. Insurance Australia Group (IAG) experience indicates that a 25 % increase in peak wind gusts can generate a 650 per cent increase in building damage claims (see figure below). The energy of the wind is proportional to the square of its velocity. This means that a 25% increase in wind speed translates into an increase in the loading on buildings and other fixed structures (associated with wind pressures and flying debris) of nearly 60%, pushing many beyond their failure thresholds and resulting in significant damage to people, property and the natural environment.

IAG BUILDING CLAIMS VERSUS PEAK GUST WIND SPEED



Source: T. Coleman 2002, op. cit., p 4.

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82 T. Coleman 2002, op. cit., p 9.

83 Ibid, p 4.

84 CSIRO 2002, *Climate Change and Australia's Coastal Communities brochure,* available at http://www.dar.csiro.au/publications/CoastalBroch2002.pdf, accessed 5 August 2004.

85 S. Changnon, Jr R. Pielke, D. Changnon, R. Styles and R. Pulwarty 2000, *Human factors explain increased losses from extreme weather and climate events,* Bulletin of the American Meteorological Society, vol. 81., pp 437-442.

86 Commonwealth of Australia (2004) *Natural Disasters in Australia :Reforming mitigation, relief and recovery arrangements.*

3.3 Climate pressures on health and infrastructure

Health

At an international level, Australians have comparatively good health status. The Australian health system is comprehensive and available to all Australian residents. As noted by the Australian Institute of Health and Welfare:

> "Australians are generally healthy, and Australia's health and wellbeing is likely to improve. Individuals are gaining a better understanding of their own health and how to maintain it; the science and practice of prevention and treatment is continually advancing; and most Australians have very good access to health services". (AIHW, 2004)[87]

Total expenditure on health amounts to 9.5 per cent of GDP[88]. Climate change may present some challenges for the health system such as improving awareness and education for health professionals and the public, improving monitoring and surveillance and extending public health services to prevent climate related illness.

Systems are in place to manage the risk of bioterrorism and emerging infectious diseases including the Australian Government's National Incident Room. This type of infrastructure provides a good basis for building on the responses to climate change induced health issues, especially the likely spread of water-borne diseases and vector-borne diseases.

Public health prevention measures may need to be enhanced to reduce the impact of heat related illness and death, including information for older Australians on coping with heat and redesign of buildings to reduce heat absorption and retention (see section on building and settlements below). Building and settlement planning is also important to reduce the impact of injury and death from storm surges, flooding and damaging winds.

Climatic conditions have wide–ranging impacts on human health, including heatstroke (a particular risk for older Australians) and the pattern of diseases and allergies. Some common examples of climate–related health impacts are outlined in Table 3.10.

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[87] AIHW, 2004 *Australia's Health 2004*, p1.

[88] Department of Health and Ageing (2004) Australian Health and Ageing, The Concise Factbook, November update, Table 4. **http://www.health.gov.au**

Table 3.10

HUMAN HEALTH AND CLIMATIC CONDITIONS

Health impact	Discussion
Temperature–related deaths	Prolonged exposure to high temperatures can cause heat exhaustion, cramps, heart attacks and stroke. Those most vulnerable to heat–related stress include the elderly, people under intense physical stress and those with cardiovascular disease. New Zealand research found that mortality increased by around one per cent per degree Celsius on hot days.
Vector–borne diseases	Includes diseases such as Malaria, Dengue Fever and Ross River Virus. The spread of these diseases has been found to be heavily influenced by climatic conditions, particularly humidity, rainfall and temperature. Malaria and Dengue Fever are no longer endemic to Australia, but a significant number of cases are imported from travellers returning from Asia. Outbreaks of the diseases most commonly occur in Queensland and the Northern Territory.
Food–borne diseases	Higher temperatures promote the proliferation of bacteria in contaminated foods and as such the incidence of cases of food–borne disease has been found to increase significantly during summer months. In Australia, 2–4 million cases of food–borne diseases are reported annually.
Water–borne diseases	Excessive rainfall events can transport faecal contaminants into waterways and drinking water supplies which can then lead to the spread of various water–borne diseases. The high density of farm animals in many parts of Australia, and the fact that many communities rely on surface water sources, means that the risk of contamination of waterways following extreme rainfall events can be relatively high. Temperature changes also affect coastal water quality with warmer waters favouring the survival and proliferation of pathogens that arise from untreated sewage piped into the ocean.
Exposure to solar radiation	Australia has one of the highest incidence rates of skin cancer in the world. The high incidence of skin cancer in Australia has been attributed to the fact that there is a predominantly pale skinned population living in an environment with relatively low air pollution, plentiful sunlight and an outdoors–oriented lifestyle. Preliminary evidence suggests that higher environmental temperatures enhance exposure to ultraviolet radiation.
Respiratory diseases	The incidence of asthma has been shown to be connected to average temperatures. There is also a demonstrated relationship between many allergen–producing organisms such as plants, mould, house mites and cockroaches, and climatic factors such as humidity, rainfall, temperature and sunshine.

Source: Department of Health and Ageing 2004, *Australian Health and Ageing System: The Concise Factbook,* Canberra, Department of Health and Ageing: Canberra Aug–04.

Climate change threatens to effect change in the pattern and incidence of these ailments over the coming years, and impact on skill and health infrastructure requirements over this timeframe. Aboriginal communities — particularly in Australia's northern regions — can be particularly exposed to these risks, and low income groups are likely to face the greatest challenges avoiding or responding effectively to climate pressures.[89]

[89] Department of Health and Ageing 2004, *Australian Health and Ageing System: The Concise Factbook.* Canberra, Department of Health and Ageing: Canberra, Aug-04.

Table 3.11

ASSESSMENT AGAINST FRAMEWORK CRITERIA — HEALTH

Vulnerability criterion	Findings
Exposure	Human health is likely to be affected directly and indirectly by increasing temperatures, the frequency of heat waves and changing patterns of rainfall. Natural disasters also expose people to physical and mental health risks.
Sensitivity	Sensitivity is high in some regions and for some populations especially for Aboriginal and Torres Strait Islander people. Vector–borne diseases, food–borne diseases and temperature related illnesses are likely to increase in Northern Australia in particular. Increased temperatures will affect older Australians.
Adaptive capacity	Australia's infrastructure to respond to quarantine, and bio–security threats, and to detect disease outbreaks through surveillance, is of high quality and improving. The health system also has capacity to mobilise health promotion campaigns as required eg for education to avoid heat stress. Land use planning, building and settlement design, and insect control measures have the capacity to moderate the influences on human health.
Adverse implications	Loss of life and the impact on hospital and emergency services through extreme weather events is likely although not predictable. There is likely to be an increased incidence of vector and food borne diseases, however this is not expected to be high if existing efforts in surveillance, quarantine and biosecurity are maintained. Some population groups are more vulnerable including remote Aboriginal communities, people on low incomes and the elderly.
Potential to benefit	Adaptive responses are feasible and likely to constitute an extension of existing strategies.

Source: The Allen Consulting Group

Energy infrastructure

The energy sector is also exposed to climate change, though the potential impacts for the sector are likely to vary by region. The impact will also depend on the uptake of environmental controls, including air–conditioning use in the domestic sector. The increased penetration of air–conditioning and other climate control units in homes is expected to continue to result in increasing demands on the energy sector — in particular, it is expected to increase the 'peakiness' of the load curve.

Demand for energy is expected to decline in the winter and increase in the summer, though these impacts are expected to vary by region. This could impact on the need for baseload generation to meet average demand, possibly leading to an increase in requirements for warmer climates but decreasing requirements for cooler regions.[90]

[90] AGO 2002, op. cit., p 27.

A study by Howden and Crimp[91] in 2001 on climate change impacts indicated that demand for energy was likely to be more sensitive to climate change in Brisbane and Adelaide than in Sydney or Melbourne. Peak demand is generally expected to be more sensitive to climate change than average energy requirements. Melbourne, Adelaide and Brisbane — which are in some cases already having difficulty meeting peak demand — are expected to be more sensitive, with Adelaide being the most affected region.[92]

The sector is exposed to extreme weather events, which could threaten infrastructure performance and security. Distribution and transmission lines and offshore platforms could possibly be subject to more frequent and severe storms, higher winds and more intense tropical cyclones. More extreme and frequent flooding could also affect the operation of hydro–electric dams. [93] Further, any increase in bushfire frequency could also impact on transmission and distribution infrastructure. Severe droughts would also affect the operation of hydro-electric generation and long term changes in the strength and frequency of winds may affect the generation of electricity from wind power.

Efficiency levels could also be affected. A 2002 study showed warming by 1°C can lead to a three per cent decrease in both thermal efficiency and transmission line efficiency.[94] Similar concerns have emerged from stakeholder consultations. – Residential air conditioner use during more frequent and severe heat waves is likely to place increasing stress on distribution systems.

Long infrastructure lead times and the long lived nature of assets indicate a need for more explicit consideration of climate change factors in Australian energy planning. Climate change potentially poses an additional threat to the reliability of power systems by accelerating demand growth, affecting production and transmission efficiencies and raising the prospect of more frequent storm related outages.

Offshore oil and gas platforms also have high exposure to climate — particularly extreme weather events. Although platforms are designed to withstand extreme conditions, frequent return periods can disrupt supply and affect the down time and safety protocols for workers on these rigs — as exemplified recently in the Gulf of Mexico.

91 S.M. Howden, H.A. Lloyd-Smith and S. Crimp 2001, *Effect of climate and climate change on electricity demand in Australia,* Proceedings of the MODSIM 2001 international congress on modelling and simulation, The Australian National University Canberra, 10-13 December 2001.

92 Ibid.

93 F.C. Cuny 1983, *Disasters and Development*, Oxford University Press, New York.

94 B. Pittock (ed) 2003, op. cit., p 138.

Table 3.12

ASSESSMENT AGAINST FRAMEWORK CRITERIA — ENERGY INFRASTRUCTURE

Vulnerability criterion	Findings
Exposure	Increasing temperature and heat waves will increase energy demand in summer. Extreme weather events, flooding and bushfires may increase the damage to infrastructure. Increased temperatures can also reduce transmission efficiency.
Sensitivity	Sensitivity is high for some regions especially Adelaide, Melbourne and Brisbane where peak demand is already stretched.
Adaptive capacity	Short term capacity is limited as infrastructure changes have a long lead time. Longer term planning is possible but requires very high capital investment.
Adverse implications	Power supply is an essential service for the economy, health, safety and households. Power outages can result in significant economic and social costs.
Potential to benefit	Adaptation planning is feasible and can fit with existing planning regimes. Winter demand for energy is likely to reduce in some regions.

Source: The Allen Consulting Group

Buildings and settlements

Buildings and settlements are directly exposed to climate change. As noted above, the impact on settlements and infrastructure could be severe, especially if acute weather events like cyclones move into areas where infrastructure is not designed to cope with them. Prolonged instances of heat, wind and rainfall, and increased variations in these phenomenon, can also lead to accelerated structural fatigue and greater demands on construction and drainage needs.[95]

Coastal infrastructure is of particular concern. Higher sea-level and more frequent extreme storm events pose substantial risk to bridges, roads, ports and coastal industry. Rising insurance costs and issues of compensation and appropriate zoning will need to be factored into future coastal planning and management.

Design standards for infrastructure are generally based on historical climate patterns that are relevant to the geographical area in question.[96] For example, commercial building standards in Australia include provisions for the building of structures such that they are protected from surface water from a 1 in 100 year storm — the frequency and severity of which is obviously based on past records.[97]

In a recent report on the effects of climate change on building design parameters, the National Committee on Coastal and Ocean Engineering (2004) notes:

95 F.C. Cuny 1983, op. cit.

96 Planning Institute of Australia Queensland Division 2002, *Climate Change and Sustainability Project: Overview of Research into Adaptation to Climate Change Through Planning,* Planning Institute of Australia (PIA) Queensland Division.

97 Australian Building Codes Board 2003, *Guide to the BCA: Class 2 to 9 buildings,* Australian Building Codes Board: Australia, p 409.

> In the past, engineers relied on the assumption that the natural environment, although highly variable, remains statistically static and that probability distributions for prime environmental factors such as wind speed, wave height, flood frequency and sea level are unchanging over time…The proven rise in carbon dioxide levels and the possibility of the Earth being subject to an enhanced 'greenhouse' effect has brought some aspects of this basis of design into question….The National Committee on Coastal and Ocean Engineering believes that the weight of scientific opinion suggests that changes to climate may occur within the design life of many coastal and engineering activities. Consequently, consideration of the possible impacts of climate change should be included in the design process.[98]

Table 3.13

ASSESSMENT AGAINST FRAMEWORK CRITERIA — BUILDINGS & SETTLEMENTS

Vulnerability criterion	Findings
Exposure	Severe weather events, storm surges and changing patterns and intensity of cyclones are likely to have a significant impact on buildings and settlements. Increased bushfire hazard, rising sea level and sustained heat waves are also key impacts.
Sensitivity	Some regions are highly sensitive, especially in Cairns, Broome, Darwin and Townsville. In particular, settlements in close proximity to bushfire prone areas and those with limited infrastructure capacity to cope with flooding.
Adaptive capacity	The long–term consequences of planning and building decisions limit the adaptive capacity of buildings and settlements. Urban management and emergency management and response arrangements allow some adaptive capacity.
Adverse implications	Damage to property can have very significant implications for individuals, industry and the longer term viability of communities. Increased risk to human life is also likely. Average annual cost of weather–related natural disasters is $900 million and this is likely to increase. Insurance industry may withdraw coverage in some regions and for climate induced damages and/or increase premiums. Destruction of property and other assets wastes resources and decreases the capital stock of the economy.
Potential to benefit	There is a strong potential to benefit from early attention to adaptation planning, especially given the long term impact of planning decisions.

Source: The Allen Consulting Group

98 National Committee on Coastal and Ocean Engineering 2004, *Guidelines for Responding to the Effects of Climate Change in Coastal and Ocean Engineering,* 2004 Update, Engineers Australia: Canberra, p 1.

3.4 Observations

These sectoral and systems analyses provide a broad overview of the issues and risks that climate change can imply. Clearly, some systems are already under pressure from the current climate and population development factors, and their capacity to respond varies. Considerable work has gone into developing these analyses, and more effort is being invested, but there is currently a clearer picture of climate dependency (and vulnerability) in some areas than others. Climate exposure will clearly differ geographically across industries and systems — as might their sensitivities and adaptation options. Sectors and industries 'unpack' into a diverse range of sub–elements, and we are only beginning to build up a detailed picture of 'on the ground' issues and capacities. This perspective has been reinforced in stakeholder consultations.

The interaction and interdependency of systems is also important. Most systems do not operate in isolation — particularly those that have been closely integrated into the social and economic dimensions of the community. The studies undertaken to date shed considerable light on the types of issues and responses that could be called forward under climate change. But there is some way to go before that picture represents a complete and holistic view of Australia's climate vulnerabilities.

Chapter 4

Regional studies of potential climate vulnerability

Climate change risks and vulnerabilities can be assessed by region as well as by sector. There are several reasons why a regional approach is a useful complement to a sectoral one:

- many practical adaptation strategies will be applied at a regional rather than sectoral scale;
- climate change impacts vary from region to region;
- some regions are more affected by climate change than others because of the negative synergies between climate change and other stressors such as population pressure or existing use of land and other natural resources; and
- two or more vulnerable sectors may be important to a particular region, with the risks and vulnerabilities of the region depending on the cumulative effect of climate change on a number of sectors.

Climate change, and its impacts, can vary significantly at a regional level. In assessing adaptation needs and priorities it is important to adopt an integrated assessment approach and link potential changes in climate conditions at a defined regional level back to the systems and activities that populated those regions. This provides for a more detailed picture of climate risks and opportunities, allows for interactions between systems and engages stakeholders in identifying omissions and weaknesses in higher level studies.

This chapter applies the report's analytical framework to a number of 'candidate' priority regions. These are:

- the Murray Darling Basin;
- south west WA;
- the Cairns and Great Barrier Reef area;
- coastal and central Queensland;
- alpine regions;
- northern Australia; and
- Australia's rangeland communities.

National stakeholder consultations were also undertaken to test these studies with stakeholders, and explore vulnerability issues and priorities for these and other regions. Details of those consultations, and stakeholder views, are reported at length in a supplement to this report. An overview of broad themes is provided below.

4.1 Regional studies

Murray–Darling Basin

The Murray Darling Basin is the largest river basin in Australia. It is significantly regulated by dams and weirs, including four major storages, sixteen weirs, five barrages and numerous other smaller structures. Roughly 40 per cent of mean annual flow is allocated to human purposes, with the majority used for irrigation.[99]

In most years, Adelaide draws more than 40 per cent of its water from the Murray. During droughts this dependence increases to more than 90 per cent. Without the regulation of the river, the population of Adelaide and many other cities and towns in the Murray Valley would be considerably smaller than they are today.

Figure 4.1

MURRAY DARLING BASIN

Source: Murray Darling Basin Commission 2003, available at: http://www.mdbc.gov.au/river_murray/river_murray_system/river_murray_system.htm, accessed on 2 August 2004.

The region is home to a biodiverse community of plants and animals, as well as manufacturing and agricultural industries:[100]

- the Basin has at least thirty five endangered birds and sixteen endangered mammals with twenty mammals being extinct;
- it is estimated that there are more than 30,000 wetlands in the Basin;
- the total area of crops and pastures irrigated in the Basin is 1,472,241 hectares. This is 71.1 per cent of the total area of irrigated crops and pastures in Australia (2,069,344 hectares – 1992 estimates);
- around 70 per cent of all water used for agriculture in Australia is used by irrigation in the Basin (1992 estimate);

[99] B. Pittock (ed) 2003, op. cit. p 87.

[100] Murray Darling Basin Commission 2004, *Basin Statistics:* available at http://www.mdbc.gov.au/naturalresources/basin_stats/statistics.htm, accessed 6 August 2004.

- the Basin is Australia's most important agricultural region, accounting for 41 per cent of the nation's gross value of agricultural production (1992 estimate); and
- manufacturing industries in the Basin have a turnover of more than $10.75 billion (1992 estimate).

Rainfall to the region is highly variable, and in 2003 two of its major water storage facilities, the Hume and Dartmouth Reservoirs, held only 4 and 21 per cent of their available capacities, respectively.

The Basin is suffering from increasing land salinisation and a decline in its water quality. Wind erosion is now also a major problem throughout the Basin, especially as it involves the loss of the finer soil particles. This has the derivative effect of reducing the soil's nutrient levels and its ability to retain moisture for plant growth, and causing declines in rural and native trees (eucalypt dieback). These factors have serious flow on implications for agriculture, biodiversity and the balance of the ecosystem.[101] Table 4.1 quantifies some of the costs associated with land degradation.

Table 4.1

ESTIMATED COSTS OF LAND DEGRADATION

Form of degradation	Cost, $ million per annum
Largely non–reversible and cumulative:	
Wind erosion of cropland	0.1
Water erosion of cropland	5.0
Reversible but requires expensive infrastructure:	
Shallow watertables (including saline) in irrigation areas	39.1
Dryland salinisation of cropland	0.4
Reversible through appropriate farm management:	
Soil acidification of cropland	25.2
Soil structure decline of cropland	144.8

Source: Murray–Darling Basin Ministerial Council 1987, *Murray–Darling Basin Environmental Resources Study,* Murray–Darling Basin Ministerial Council: Canberra, p 54.

Thus due to dams, irrigation, urban development and tensions in water regulation and allocation regimes, the Murray Darling Basin is widely recognised to be under severe stress as a result of reduced water flows. These current conditions have rendered the region highly sensitive to climate change.

Climate threat and potential system impacts

The dominant impacts of climate change on the region are likely to be reduced rainfall and more frequent and intense droughts. Combined with other climate change factors, the potential impact of climate change on both natural and human systems is expected to be significant.

[101] A. Glanznig 1995, *Native Vegetation Clearance, Habitat Loss and Biodiversity Decline,* Biodiversity Series Paper No. 6 Biodiversity Unit, Department of Environment, Sport and Territories: Canberra.

Natural systems

CSIRO modelling indicates that climate change is likely to reduce rainfall within the Murray Darling basin. Stream flows within the region are expected to vary by 0 to –20 per cent by 2030 and +5 to –45 per cent by 2070. This could lead to water shortages and a corresponding increase in competition between water users, especially where large diversions to river systems are made for industry and irrigation.[102]

In particular, modelling of the Macquarie River catchment indicates that climate change would likely decrease streamflow into the Burrendong Dam, which is the main storage in the catchment.[103] A study by Jones[104] has examined some of the consequences of this streamflow reduction. For bird breeding events, a biophysical threshold was established at 350 giga–litres of reduced stream inflows for ten successive years. By 2030, this threshold was found to be exceeded by 20 to 30 per cent in a 'drought–dominated' scenario.

The ENSO phenomenon also raises the spectre of periodic drought for the region. The surface effects of drought include drying of the earth, increasing wind gusts and desertification,[105] which could possibly impact infrastructure, agriculture, biodiversity and the water supply. As noted by the AGO, while flora and fauna tend to recover quickly from flooding, recovery from drought is far slower and often incomplete. This can facilitate invasion into the region by exotic and introduced species, threaten the viability of riverine and aquatic species, and disrupt biotic composition.[106]

Climate change is also likely to accelerate woody weed infestation. This has already been occurring over much of the arid and semi–arid Western Division of NSW and areas to the north in Queensland. Woody weeds are native species that compete with and exclude other plants. These plant species are unpalatable to livestock and in some cases, inedible. According to the Murray Darling Basin Commission, woody weeds — when combined with overstocking — can result in soil erosion which again harms agriculture and the ecosystem's biodiversity. Further, control of woody weeds is difficult and costly.[107] Conversely, increasing temperatures and declining rainfall are likely to accelerate the loss of some native and rural trees.

Human systems

In terms of agricultural losses, some estimates suggest that in the Murray Darling Basin, where irrigated agriculture accounts for around 70 per cent of all water used, climate change could impose costs to agriculture in the order of $0.8–1.2 billion in net present value terms.'[108] These losses may be incurred due to increasing soil salinity levels,[109] topsoil loss and water erosion in periods of flooding and increased competition which could reduce the supply of water for irrigation.

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102 CSIRO 2001, op. cit., p 7.

103 AGO 2002, op. cit., p 15.

104 R.N. Jones 2001, *An Environmental Risk Assessment/Management Framework for Climate Change Impact Assessments,* Natural Hazards, vol 23., pp 197-230.

105 F.C. Cuny 1983, op. cit.

106 B. Pittock (ed) 2003, op. cit., p 102.

107 MDBC 2004, Land Degradation, found at http://www.mdbc.gov.au/education/encyclopedia/naturalresources/env_issues/land_degradation.htm#Table%205, accessed 6 August 2004.

108 AGO 2002, op. cit., p 20.

109 The change in soil salinity is not expected to be uniform. In some areas, climate change is likely to lead to increases in river salinity, exacerbating agricultural production losses; in other areas, the reduced rainfall is

A decrease in stream flows into the Macquarie River catchment as a result of climate change can also impact on human activities. Jones[110] has investigated critical thresholds for irrigation allocations under different availability scenarios. A 50 per cent reduction in irrigation water allocations for five consecutive years was assumed to cause the economic failure of the farmer. By 2030, this threshold was found to be exceeded by 20 to 30 per cent in a 'drought–dominated' climate scenario.

Table 4.2

ASSESSMENT AGAINST FRAMEWORK CRITERIA — MURRAY DARLING BASIN

Vulnerability criterion	Findings
Exposure	The Murray–Darling Basin (MDB) is likely to experience reduced annual average rainfall and increased temperatures leading to an overall drying trend. More frequent and severe drought is also possible.
Sensitivity	Sensitivity is high. Water is already over–allocated and climate change impacts will exacerbate the difficulties associated with managing demand and water quality. Agriculture, biodiversity, natural systems and the quality of water for towns and cites are likely to be significantly affected.
Adaptive capacity	Adaptive capacity of the agricultural systems is high, although this will take planning and some time to realise. There is considerable scope to adapt to reduce run–off through measures already under investigation such as changes to the allocation of water (including trading and price mechanisms) and water conservation measures.
Adverse implications	The MDB accounts for about 40% of Australia's agricultural production. Adelaide draws a significant proportion of its drinking water from the Murray. There are an estimated 30,000 wetlands in the MDB supporting important populations of migratory birds.
Potential to benefit	There are considerable potential benefits in taking climate change into account when planning for future management of resources, particularly water, in the Murray–Darling Basin.

Source: The Allen Consulting Group

Southwest Western Australia

The southwest of Western Australia is another region vulnerable to the effects of climate change.

The area is the most densely populated region of Western Australia and home to a number of growing industries. Timber, wool, dairy and beef industries are significant drivers of the southwest's economy, as is wheat farming. Grapes are also grown in the Margaret River area. The region also supports significant biodiversity — including tall forests of Karri and Jarrah — which are features for the tourism industry.

expected to reduce the recharge to groundwater tables — which would stem the onset of dry land salinity in the region. Thus, the impact will depend on the timing and character of climate change.

110 R. N. Jones 2001, op. cit., pp 197-230.

Figure 4.2

SOUTHWEST WESTERN AUSTRALIA

Photo: Tony Karacsonyi

Like many other regions in Australia, the southwest is under significant stress due to poor land management. Land clearing for agricultural purposes has created salinity problems for many areas and impacted on the region's biodiversity. These stresses have increased the region's sensitivity to further climate–related changes.

Furthermore, south western Australia is arguably already feeling the effects of climate change. This region has seen a 10 to 20 per cent decrease in its winter rainfall over the last 30 years and in tandem with this, temperatures have also increased substantially over the last half century. Studies by the Indian Ocean Climate Initiative (IOCI) have indicated that the decrease in rainfall has been accompanied, and 'apparently associated with', a change in the large scale global atmospheric circulation, which is consistent with changes projected by global climate models incorporating anthropogenic forcing.

However the IOCI also points out that there is not sufficient evidence to indicate that the enhanced greenhouse effect alone is responsible for the shift in rainfall levels and temperature patterns. Most likely, the climate changes are a function of both natural variability and anthropogenic change.[111] Nevertheless, these climate pressures remain, and science suggests that, given ongoing greenhouse gas emissions, they are likely to continue into the future as on overlay on 'natural' occurrences.

Dramatic changes in rainfall levels and temperature have led to a sharp decline in water flows, leading to environmental degradation and pressure on water supplies and quality. Major investment in desalinisation plants are now being considered as a means of ensuring continued urban water supplies.

Climate threat and potential system impacts

This region of Australia is particularly exposed to climate change by way of increasing temperatures and reduced rainfall. Together these trends could lead to increasing patterns of droughts and flooding within the region, marked by an overall reduction in average annual rainfall levels.

111 Indian Ocean Climate Initiative 2002, op. cit.

Natural systems

Heathland systems in this area exhibit high levels of biodiversity and are already under pressure from habitat fragmentation and salinity. They are also trapped from further southward migration as temperatures warm.

A recent study by the AGO of climate change and woodland ecosystems in the region found that the *Dryandra* and *Acacia* species would be significantly reduced, even with only a 0.5°C rise in temperatures, holding precipitation constant. Other varieties of plant life could also be vulnerable, along with sensitive animal species. A survey of the literature and discussions with stakeholders highlighted the need for a much better understanding of the implications of climate change for native and feral species, and specialised habitats.

Human systems

Declining rainfall patterns are expected to greatly reduce plant production in pastures, which in turn is expected to constrain animal production. Heat stress could possibly exacerbate this trend.[112], and add to water scarcity problems.

Rangeland communities of the region are expected to be adversely affected by warmer temperatures, changing rainfall and increased CO_2 levels, which may accelerate shifts in vegetation towards so–called woody weed species. This may in turn also depress animal productivity.

However there could be some benefits to the region. Wheat production could increase — even if rainfall declines by 20 per cent across the wheat belt — provided that temperatures do not increase by more than 2°C. These benefits are somewhat offset by declining protein content induced by the carbon dioxide levels.

Forestry might also benefit — depending on the rate and magnitude of climate change. CSIRO has suggested that the forest industries could see an expansion of between 25 and 50 per cent, assuming a warming of 3°C, a doubling of CO_2 levels and no change in rainfall.[113]

Changing water temperatures and shifting ocean currents might also impact WA fisheries.

Further discussion of regional issues and perceived vulnerabilities is provided in the supplement to this report, in the context of the WA roundtable meeting.

112 AGO 2002, op. cit., p 21.
113 CSIRO 2001, op. cit., p 4.

Table 4.3

ASSESSMENT AGAINST FRAMEWORK CRITERIA — SOUTH WESTERN AUSTRALIA

Vulnerability criterion	Findings
Exposure	The Southwest corner of Western Australia (SW of WA) is likely to experience increasing temperatures, further reductions in rainfall, increasing drought periods and reduced winter flooding rains. The region's winter rainfall has already declined 10–20% over the past 30 years.
Sensitivity	Sensitivity is high. Natural ecosystems and species with specialised habitats are likely to be severely affected. Urban areas are sensitive to reduced water supply. Agriculture is also sensitive, although there may be some offsetting benefits in the short term.
Adaptive capacity	Adaptive capacity of the agricultural systems is high, although this will take planning and time to realise. Natural ecosystems have little autonomous adaptive capacity. Urban water supply requires careful long–term planning.
Adverse implications	Agriculture in the SW of WA will be affected. The wheat harvest could be reduced by up to 15% (Pittock). There is potential for the loss of native species with a narrow annual mean temperature range in a region that is an internationally important biodiversity 'hot spot'.
Potential to benefit	There is considerable potential for benefit from careful planning, especially in the urban water sector. Human intervention will be required to maximise the prospects of maintaining the important biodiversity in this region.

Source: The Allen Consulting Group

Cairns and the Great Barrier Reef

Cairns and the Great Barrier Reef provide an excellent example of the interdependencies between human and ecological systems. Like similar coastal areas along northern Queensland, this region is also highly vulnerable to climate change.

The Great Barrier Reef, one of Australia's sixteen World Heritage Areas, is already stressed by changes in ocean temperatures, nutrients and stream flow. Marine systems, like coral reefs, are highly sensitive to change, having evolved within a narrow temperature band. The Great Barrier Reef has experienced coral bleaching events in recent years, although not as extensively as reefs elsewhere in the world, and suffers periodically from attacks by the crown of thorns starfish. Run–off from on–shore agricultural production can also periodically affect water quality.

Importantly, while the Great Barrier Reef is a high profile tourist destination and deservedly recognised world–wide, reef systems in other parts of Australia (including, for example Ningaloo Reef off Western Australia) are also likely to be affected by climate change.

Figure 4.3

CAIRNS AND THE GREAT BARRIER REEF

Photo: Department of Foreign Affairs and Trade Overseas Information Branch

Cairns, as a low–lying coastal settlement, is highly susceptible to flooding and surge associated with cyclone activity. Extreme weather events pose a serious threat to its infrastructure and coastal resorts. Cairns also benefits from reef and rainforest tourism – which is the major income source for the region.

Cairns also supports a large commercial fishing industry that catches prawns in the rich waters of the Gulf of Carpentaria and Torres Strait. The port services freighters from around the world, and has given rise to a ship building industry, though this is largely dominated by a single company (NQEA).

The region is also home to a number of agricultural industries — including fruit, livestock and sugar industries.[114] Sugar cane is the dominant crop in North Queensland, but other crops include bananas, mangos and tobacco. Table 4.4 overviews major contributors to the regional economy.

[114] See Cairns Connect website: http://www.cairnsconnect.com/cairns/industry.asp

Table 4.4

CAIRNS INDUSTRIES

Industry	Value per annum ($ millions)	Contribution to Cairns' economy (%)
Tourism	1,200	40%
Agriculture	564	20%
Mining	428	14%
Manufacturing	330	11%
Fishing	230	8%
Other	200	6%
Total	**2,952**	**100%**

Source: Cairns Connect website: http://www.cairnsconnect.com/cairns/industry.asp

Climate threat and potential system impacts

Natural systems

The biodiversity of the region is highly exposed to increasing temperatures, changing rainfall patterns and extreme weather events. Higher temperatures may contribute to coral bleaching and mangrove losses, as well as a loss of marine species that are heavily reliant on these ecosystems. Rainforests could also see a shift in species balance.

Biodiversity is likely to be significantly affected by climate change due to the limited ability of natural systems to keep pace with the pressures for adjustments brought about by climate change:[115]

- Initial work in North Queensland has projected that a 1°C increase in temperature could significantly reduce — possibly by up to 50 per cent — the upland tropical rainforests. This rainforest loss may threaten rainforest vertebrates, which are expected to see a corresponding decrease in species numbers, to a mean of 63 per cent of the current range of endemic species.
- Coral reefs are highly exposed and sensitive to water temperature changes. An increase of 1°C to 2°C in water temperature would cause significant distress to corals. Projections from global climate models indicate that such thresholds may be reached within the next few decades.

Human systems

The dependence of the Cairns region on natural environmental features as a major source of income underlines its potential vulnerability to climate change. A range of closely related human systems stand to be affected.

Tourism could suffer significant declines over the long term as reefs and rainforests are affected — although concerns about the viability of these natural treasures might bring forward demand in the short term (and add to non–climate pressures).

[115] AGO 2002, op. cit., pp 17-19; IAG 2004, op. cit., pp 26-28; and B. Pittock (ed) 2003, op. cit., pp 88-89.

Changing storm and precipitation patterns could also affect the industry. One study suggests that the intensity of tropical cyclones in Queensland could increase by up to 20 per cent by 2050. This, coupled with increases in sea level could result in flooding of roughly two times the coastal area historically affected, and significant inundation within the City of Cairns.[116]

Storm activity can also threaten the agriculture sector, while changes in temperature and other climate variables can affect growing conditions and the incidence of pest species.

These threats are being extensively examined by the Queensland government and stakeholders, and planning around reducing climate change impacts in North Queensland and other areas is well advanced. The Cairns local council has also been active in this area, through its planning and public works.

A fuller discussion of issues and responses is provided in the supplement to this report.

Table 4.5

ASSESSMENT AGAINST FRAMEWORK CRITERIA — CAIRNS AND THE GREAT BARRIER REEF

Vulnerability criterion	Findings
Exposure	Increased sea and land surface temperatures and an increase in the number and severity of storms and cyclones are likely.
Sensitivity	Both the Great Barrier Reef and the Wet Tropics are very sensitive to changes in temperature; an increase of as little as 2°C could have devastating effects. Increased storm surges and cyclone intensity could cause serious damage to Cairns, with potential for property damage and loss of life.
Adaptive capacity	Autonomous adaptive capacity of natural biological systems is low.
Adverse implications	The Great Barrier Reef and the Wet Tropics are high profile and popular tourist attractions and World Heritage Areas. Tourism accounts for 16.3% of employment in Tropical North Queensland.
Potential to benefit	There is considerable scope to increase the resilience of natural systems by reducing other stresses. Settlements could benefit from attention to urban and natural disaster management planning.

Source: The Allen Consulting Group

116 CSIRO 2001, op. cit., p 7.

Coastal and central Queensland

This region includes the Queensland coast south of Townsville and the areas inland from this stretch of coastline.

Figure 4.4

COASTAL SETTLEMENT IN QUEENSLAND

Photo: Department of Foreign Affairs and Trade Overseas Information Branch

The Brisbane–Gold Coast region is experiencing rapid population and economic growth, which has created additional demands on the energy and water supply utilities. The use of electrical consumer goods — particularly air conditioners — has been one of the contributing factors to this increased demand. The projected decrease in rainfall in the region and the anticipated increase in storm surges is likely to increase the demand for energy and affect the energy supply infrastructure.

Many coastal areas of Queensland already experience substantial impacts from storms including flooding. The projected sea–level rise and increased storm frequencies will increase these risks particularly to urban infrastructure. Rainfall is projected to decrease in some areas of Queensland including the south–east of the State and temperatures are projected to increase. Research has indicated that heat waves and the incidence of vector–borne diseases (Dengue fever, Ross River virus and Barmah Forest virus) are likely to increase, affecting vulnerable populations in particular.[117]

The Queensland State Coastal Management Plan includes some adaptation measures to deal with the impacts of climate change. The State Government is also seeking to integrate adaptation measures into other key planning instruments such as the regional plans.

[117] Queensland Government 2004, *Queensland Greenhouse Strategy*.

Table 4.6

ASSESSMENT AGAINST FRAMEWORK CRITERIA — COASTAL & CENTRAL QUEENSLAND

Vulnerability criterion	Findings
Exposure	This region is likely to experience significant drying, increased temperatures, and more extreme events, notably storms, storm surges and heatwaves.
Sensitivity	Rapid population growth in the Brisbane–Gold Coast conurbation is expected to continue, increasing sensitivity to drying (with consequent demands on already stretched urban water supplies and electricity generation and distribution systems) and extreme events. Inland agricultural production may be threatened by drying. Increased temperatures could impact on health outcomes especially older Australians retiring to Queensland coasts.
Adaptive capacity	Capacity to prevent storm and flooding damage to new infrastructure is high if planning and building regulations take account of the projected climate change. Existing infrastructure remains vulnerable. Agricultural systems have high adaptive capacity.
Adverse implications	There are indications that insurance companies will withdraw coverage for some areas and for storm events. Agricultural activities important for the regional economy could be at risk. Heatwave related ill health in existing poor housing design is highly likely.
Potential to benefit	There is considerable potential to benefit from adaptation planning, particularly in infrastructure and development planning.

Source: The Allen Consulting Group

Alpine areas

The Australian alpine and sub–alpine areas cover a relatively small area of Australia including parts of Tasmania (Central Plateau and Ben Lomond), Victoria (around Mt Bulla, Mt Buffalo and Mt Bogong) and NSW/ACT (from Mt Kosciusko to Mt Gingera). Each of these areas contain unique biota and have tourist resorts — mainly for skiing in winter, and act as important water catchments.[118]

[118] Commonwealth of Australia 2004, *Potential effects of global warming on the biota of the Australian Alps*, A report for the Australian Greenhouse Office by Drs Pickering, Good and Green.

Figure 4.5

ALPINE HABITAT

Photo: Department of the Environment and Heritage; John Baker

Climate change, in particular increasing temperature and reduced rainfall, are projected to impact on the natural ecosystem. Sensitive communities such as fens and bogs are predicted to decrease, while some dominant species such as tall alpine herbfields could increase in occurrence and distribution. Native fauna with narrow environmental tolerances, such as the Mountain Pygmy Possum, are projected to suffer greatest impact. Other native species may benefit from an increased habitat range. Pests and weed species may also increase their distribution.

The future attraction of alpine areas as a tourist destination, especially for winter skiing, could be affected. This will affect the alpine resorts, nearby towns, en–route towns and the equipment and clothing retailers. The lower altitude resorts are likely to be the most significantly affected with the higher resorts having the capacity to increase their artificial snow making.[119] All resorts have the potential to further encourage non–winter based tourism.

The Victorian Government has recently released its *Alpine Resort 2020 Strategy* which predicts that the high altitude resorts "will maintain sufficient snow cover to remain attractive, viable resorts for snow sports until at least the year 2020" and that there are opportunities to expand non–winter recreation[120].

The alpine and sub–alpine regions are also important as water catchments. The projected increasing incidence of bushfires will impact on this function. For example, the 2002–03 summer bushfires in NSW and the ACT had a significant impact on the quality and reliability of the water supply for Canberra.[121]

[119] The State of Victoria 2002, *Alpine Resorts 2020 Discussion Paper*. Department of Natural Resources and Environment.

[120] The State of Victoria 2004, *Alpine Resorts 2020 Strategy*, Department of Sustainability and Environment.

[121] CRC for Catchment Hydrology, http://www.catchment.crc.org.au/bushfire/index.html

Table 4.7

ASSESSMENT AGAINST FRAMEWORK CRITERIA — ALPINE AREAS

Vulnerability criterion	Findings
Exposure	Increasing temperature, reduced rainfall, bushfires and reduction in snow cover is likely.
Sensitivity	Sensitivity is very high for some species with narrow environmental tolerances (e.g. Mountain Pygmy Possum). The reduction in snow cover and quality will limit the tourism attraction for skiing during winter.
Adaptive capacity	It is predicted that some species of plants and birds will be able to adapt to the climate change (e.g. heathland and some birds), while other are unlikely to be able to adapt. Skiing operators have shown high adaptability to the reduction in snow cover during winter.
Adverse implications	The ski industry contributes about $550 million to the national economy. There are estimates that reduced natural snow cover could result in as much as 44 per cent of this market being lost, although these losses could be offset by diversification into other tourism activities. Alpine regions contain a number of unique species at risk from climate change.
Potential to benefit	There is significant potential for the tourist industry to benefit from adaptation planning. Adaptation planning for biodiversity is more difficult.

Source: The Allen Consulting Group

Far Northern Australia

This region covers the tropical north of Australia from Cape York Peninsula to the Kimberley. It includes ecologically important wetlands such as Kakadu and many culturally significant areas for Aboriginal and Torres Strait Islander people. The region is characterised by the wet–dry monsoonal climate, its remoteness and a rich diversity of habitats. Mining and tourism make up the bulk of the industry activity[122]. There are a high proportion of Indigenous Australians in the region with many living in remote locations.

The projected sea level rise, increased intensity of cyclones and extreme rain events, and increased temperatures are expected to have significant impacts on the region's people and biodiversity.

The low–lying freshwater wetlands are projected to suffer from salt water intrusion. The World Heritage areas such as Kakadu National Park and Mary River Catchment are particularly vulnerable. These wetlands are major conservation zones for plants, fish, reptiles and migratory birds[123] and are significant tourist destinations.

122 Northern Territory Treasury 2003, Economic Overview, the Territory Economy Online www.nt.gov.au/ntt/economics

123 R.A. van Dam, C.M. Finlayson and D. Watkins (eds.) 1999, Vulnerability assessment of major wetlands in the Asia-Pacific region to climate change and sea level rise, Supervising Scientist Report 14, http://www.deh.gov.au/ssd/publications/ssr/149.html

The Australian and Northern Territory Governments have undertaken a project to evaluate the costs and benefits of options to prevent the intrusion of salt water into the Mary River Wetlands. The study found that salinity mitigation would deliver significant benefits – mainly in avoiding the loss of agriculture, fisheries and tourism.[124] Whether salinity mitigation is viable for all northern wetlands would need to be explored.

Indigenous people live along many of these northern wetland areas. Increasing storm surges and cyclone intensity will create infrastructure damage to road, rail and electricity services and increase the isolation of many communities from road flooding and damage.

The Kimberley region has a diverse economy including mining, tourism, irrigated agriculture, pastoral industry and pearling. The tourism industry is expected to expand. About half of the population are Aboriginal people.[125] The Kimberley region is projected to have increased monsoonal rain which would increase fuel load and create conditions for increased bushfires in the dry season. Fire is known to affect the survival of some plants and animals and the projections are for increased frequency and intensity of fires in the region.

Table 4.8

ASSESSMENT AGAINST FRAMEWORK CRITERIA — FAR NORTHERN AUSTRALIA

Vulnerability criterion	Findings
Exposure	Sea level rises, more intense tropical cyclones, increased incidence of extreme rain events, and increased temperatures are likely.
Sensitivity	This region contains a number of low–lying freshwater wetlands that would suffer saltwater intrusion with relatively modest sea–level rise. Remote communities would become more isolated with more frequent extreme events if land transport links were severed. Conditions may become more conducive to the spread of vector–borne diseases, and increased heat may also exacerbate existing health problems. There is also the possibility that changes in the natural landscape may affect the cultural life of Indigenous people, although this requires further investigation.
Adaptive capacity	Low lying wetlands have little autonomous adaptive capacity. Some remote communities may lack the resources to develop effective adaptation responses.
Adverse implications	Kakadu is listed on the World Heritage register for both natural and cultural values and is an important source of tourism revenue. Other wetlands also have important ecological, cultural and economic values.
Potential to benefit	Options for protecting low lying wetlands from saltwater intrusions are feasible. Planning for natural disasters could be strengthened.

Source: The Allen Consulting Group

[124] Commonwealth of Australia 2004, *Cost-benefit analysis of Mary River Wetlands Salinity Mitigation – an overview,* Undertaken in conjunction with the NT Department of Infrastructure, Planning and Environment.

[125] Government of Western Australia 2003, *Kimberley Economic Perspective.*

Rangeland communities

Area profile

Rangeland communities are particularly vulnerable to climate change. These communities are part of rural Australia accounting for roughly 75 per cent of Australia's total land area.

Figure 4.6

RANGELAND COMMUNITIES

According to Rangeland Australia, Australia's rangelands are home to sparsely settled communities supporting 2.3 million people (13 per cent of Australia's total population). Roughly 18 per cent of Australia's rangeland communities are Indigenous people. The common denominators among these communities are:

- the rangeland is arid or semi–arid, such that rainfall is insufficient or too variable to support cropping;
- the rangelands are marked by a great diversity of plant and animal species; and
- economies tend to be resource based.

Table 4.9 summarises the contribution of some of the region's major industries.

Table 4.9

RANGELAND INDUSTRIES

Industry	Value per annum
Mining	$12 billion
Cattle and beef	$4.4 billion
Tourism	$2.0 billion
Sheep and wool	$1.0 billion
Flora and fauna harvesting	$190 million[126]

Source: Rangelands Australia, available at http://www.rangelands–australia.com.au/ra_fset2.html

In addition to its economic value, the rangeland communities support other important, non–market based aspects of Australian culture:

- approximately 18 per cent of Australia's rangelands are under Aboriginal ownership and management;
- the rangelands are ecologically important because of the significant number of endemic species and habitat for rare, threatened and endangered species; and
- the rangelands are rich in biodiversity, with 1,800 types of plants and 605 vertebrate animals currently identified. Further, the rangelands represent 11 per cent of all listings on the Register of the National Estate and include five World Heritage sites.

[126] This includes native seeds, bushfoods, cut flowers, kangaroo harvesting, emus and goat production.

These communities are highly exposed and sensitive to climate change. Inappropriate land management practices and introduced species, such as rabbits, for the rangelands have contributed to soil salinity, accelerated soil erosion, an increase in the number and distribution of weeds and feral animals, reduced water quality and decreased biodiversity.[127] Thus, even small changes in climate could have a large impact within the region.

Climate threat and potential impacts

Because rangeland communities cover such a broad area, the potential impact of climate change on these areas is expected to be mixed. On balance, rainfall patterns appear to be the chief concern for the rangelands,[128] as this impact is expected to dominate increases in plant growth due to increased CO_2 levels. Rainfall in the region is expected to vary in accordance with the increasing frequency of the ENSO phenomenon, which may produce a drought–flood pattern of rainfall across Australia.

Natural systems

In the south, the supply and quality of water may be adversely impacted by drought and the degradation of catchment areas. This could possibly accelerate the loss of some native woodland and shrubs in some areas, but help alleviate salinity problems.

In the north where heavy rainfall events are expected to be larger and more frequent, with average rainfall level increasing, dryland salinity could increase, as will run–off distribution.[129] If these projections are realised, this could also adversely affect the vegetation balance, and result in a higher incidence of invasive woody weeds. Overall there is a high degree of uncertainty with regard to the implications of climate change in these areas due to the large area covered and commensurate variability in climate conditions.

Human systems

In the south of Australia, where rainfall is expected to decrease, rangeland communities could see declines in animal production. According to CSIRO:

> If rainfall decreases in southern Australia by more than 10 per cent in winter and spring — the main growing seasons for herbage in this area — then forage and animal production will be reduced.[130]

Conversely, plant and animal production may increase in northern regions due to increased precipitation. As noted by the AGO:

> In monsoonal northern Australia, with little projected change in summer rainfall (the main growing season for pastures in that area) higher CO_2 levels should have a positive impact on plant production in these areas, but these pastures are already severely nutrient limited. [However] decreases in forage quality may reduce some of the potential animal production benefits in the monsoonal region. Over 40 per cent of the Australian cattle herd grazes on tropical and sub–tropical pastures in Queensland in non–monsoonal areas that are strongly affected by ENSO.[131]

However, heat stress, flooding and pests are also an important consideration. These can affect productivity in the region, but also have important implications for human health and wellbeing.

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127 B. Pittock (ed) 2003, op. cit., p 99.

128 Ibid.

129 Ibid.

130 Ibid.

131 Ibid, p 20.

Low income and isolated Indigenous communities may come under significant additional pressures from climate change. Consultations highlighted the relevance of such issues, but there is little analysis at present to confirm the potential extent of the problem.

Table 4.10

ASSESSMENT AGAINST FRAMEWORK CRITERIA — RANGELANDS

Vulnerability criterion	Findings
Exposure	Decreased rainfall is likely in the more southerly rangelands. Likely trends in the north are less certain. Extreme rainfall events are likely to become more frequent and dry spells are likely to grow longer.
Sensitivity	The rangeland environment is very sensitive to climate change, and this sensitivity is increased by inappropriate land management practices and introduced species. Major changes in vegetation cover are likely. Increased land degradation, including salinisation, is possible. Carbon dioxide fertilisation may offset some of the negative effects of reduced rainfall on pasture production.
Adaptive capacity	A major study of historical land degradation episodes associated with drought suggests that adaptive capacity is moderate but could be enhanced by improved management.
Adverse implications	Rangelands support a population of approximately 2.3 million people. The annual value of tourism and agricultural production in rangelands is about $6.4 billion. There may be significant declines in agricultural production in the southern rangelands as a result of climate change.
Potential to benefit	There is potential to benefit from adapting management practices to changed climate.

Source: The Allen Consulting Group

4.2 Regional stakeholder perspectives

The regional studies provide a useful lens for focusing stakeholder discussions on the uncertainties and gaps in existing climate change studies, and future needs.

A full account of the roundtable discussions undertaken as part of this study is available as a supplement to this report. It adds considerable detail and context to the sectoral and region analysis contained in these chapters. It highlights additional threats, opportunities and issues as well as concerns about our current level of knowledge regarding the details of climate change and its potential effects on important systems.

Various Australian jurisdictions have been actively developing and pursuing climate change adaptation agendas. The Victorian government, for instance, has recently funded high resolution CSIRO modelling for that State (which disaggregates Victoria into 6 climate regions) and highlighted these findings in a public release consultation paper on adaptation needs within the region.[132] The Queensland and Western Australian governments have also adopted a strong focus on climate risks and adaptation needs, given their long coastlines, exposure to weather systems likely to be significantly impacted by climate change and the importance of agriculture and/or tourism in their economies. The Indian Ocean Climate Initiative (IOCI) in WA makes a very important contribution to climate research and information dissemination agenda in WA, and Queensland has recently embraced the need to lay a foundation for adaptation to climate change as part of the Queensland Greenhouse Strategy (launched 4 May 2004). Other States and Territories are also putting an increasing emphasis on adaptation in their mix of climate change objectives and responses.

A range of government and private stakeholders participated in the roundtable discussions – held in each Australian capital. Common themes from these discussions relating to vulnerability assessment were:

- a strong and consistent emphasis on the need for higher resolution climate studies (i.e. allowing more regional detail to be discerned) and a greater focus on the probability of different scenarios and outcomes;
- a desire for the modelling to better reflect other, non climate–related trends such as demographics and internal migration, and that these extant trends could materially impact on the assessment of potential future climate change impacts;
- probabilities and boundaries need to be more rigorously applied to uncertainty;
- a need to better understand how different structural trends will interact (such as ageing of the population, trends towards more single person households, increased energy loads associated with climate change) and integrate these into advice on future pressures and outcomes;
- sectoral and regional interdependencies (including international) need to be more fully considered;
- the need for a better understanding of the climate pressures impacting on natural ecosystems and species — and what could be done about them;
- the importance of local governments in ‘hardening’ the urban environment against climate change; and
- the need for communication, planning and preparatory effort by all levels of government and industry as part of a national adaptation response.

These themes highlight the need for further analysis and information provision as an input to adaptation planning. They also point to a mix of responsibilities and actions that need to be taken into account in Australia’s adaptation response, and in the identification of priority areas for research and policy development.

[132] Victorian Government 2004, *Adapting to Climate Change – Enhancing Victoria’s Capacity*, Department of Sustainability and Environment: Melbourne, July, 2004.

While a clearer picture is emerging on the possible climate changes that will play out across Australia’s regions, and the potential impact these might have on exposed and sensitive systems, there is still more analysis to be done to fill knowledge gaps. The adaptive capacity of affected systems, and the most effective strategies that are likely to be employed in certain systems and regions is perhaps one of the less developed areas of our current knowledge. However, it is possible to make educated judgments about the adaptive capacities of systems based on past observation, and identify key characteristics that will be critical to their ability to deal effectively with climate change in the timeframes likely to apply.

Chapter 5

Adaptation: private perspectives and policy priorities

The world in which we live is inherently dynamic. Biological, social and economic systems have developed against this backdrop and therefore have an inherent ability to cope with change and deviations from 'normal' levels. However, climate change raises the spectre of shifting and more variable climate conditions and the need to cope with more frequent and energetic extreme weather events.

It is clear that all systems will feel some pressure from climate change. A key focus of adaptation policy is to reduce the adverse consequences, and capitalise on any opportunities, arising from climate change. However this objective, while simply stated, is challenging in practice. Adaptation planning is complicated by profound uncertainties — uncertainties in both the probabilities and consequences of climate change, and in the adaptive responses of affected systems. Attitudes can also differ on when and how to respond to an emerging threat or opportunity. Yet in some instances, failure to act may lead to serious or even disastrous consequences, and a delayed response can mean that even higher costs may need to be faced in the future.

This chapter examines:

- incentives and decision frameworks likely to underpin the level and timing of adaptation responses;
- the role for governments and policy makers in facilitating 'efficient' adaptation and representing wider community interests; and
- priority sectors and regions for further research and developmental effort under the National Climate Change Adaptation Programme, aimed at enhancing the effectiveness and pay–off of government expenditures in this area.

5.1 Adaptive capacities and options

Different systems have varying levels of adaptive capacity. The capacity of a system to respond depends critically on its options for adaptation and the resources available for a response. Furthermore, there also exist a wide range of responses to the threat of climate change, which have been summarised by the United Nations Environment Programme.[133] Although existing literature has generally used this adaptation response framework in the context of public policy decisions, it is equally relevant to private thinking on climate change. These measures, which are not mutually exclusive options, canvass the complete range of general responses available to actors:

- *Bear the loss.* All other adaptation measures may be compared with the baseline response of 'doing nothing' except bearing and accepting the losses. In theory, bearing loss occurs when those affected have no capacity to respond or where the costs of adaptation measures are considered to be high in relation to the risk or the expected damages.

[133] J.F. Feenstra, I. Burton, J.B. Smith, and R.S.J. Tol 2003, *Handbook on Methods for Climate Change Impact Assessment and Adaptation Strategies,* Institute for Environmental Studies: Amsterdam.

- *Share the loss.* This type of adaptation response involves sharing the losses among a wider community. Such actions take place in traditional societies and in the most complex, high tech societies. Large–scale societies share losses through public relief, rehabilitation, and reconstruction paid for from public funds. Shared losses can also be achieved through private insurance.
- *Modify the threat.* For some risks, it is possible to exercise a degree of control over the environmental threat itself. When this is a 'natural' event such as a flood or a drought, possible measures include flood control works (dams, dikes, levees).
- *Prevent effects.* A frequently used set of adaptation measures involves steps to prevent the effects of climate change and variability. Examples can be found in agriculture, such as changes in crop management practices including increased irrigation water, additional fertiliser, and pest and disease control.
- *Change use.* Where the threat of climate change makes the continuation of an economic activity impossible or extremely risky, consideration can be given to changing the use. For example, a farmer may choose to substitute a more drought–tolerant crop. Similarly, crop land may be returned to pasture or forest, or other uses may be found.
- *Change location.* A more extreme response is to change the location of economic activities. For example, relocating major crops and farming regions away from areas of increased aridity and heat to areas that are currently cooler and which may become more attractive for some crops in the future.
- *Research.* The process of adaptation can also be advanced by research into new technologies and new methods of adaptation.
- *Educate, inform and encourage behavioural change.* Another type of adaptation is the dissemination of knowledge through education and public information campaigns, leading to behavioural change.

Different situations will require a different mix and sequencing of responses, with the need to assess each set of risks and opportunities on its merits.

Depending on the characteristics of the system, it may implement an autonomous or planned response. The autonomous adaptation is a response to change as it occurs, essentially a response induced by realised climate trends or events. Both human and natural systems will adapt autonomously to climate change. By contrast, planned adaptation is a response in anticipation of an event.

Figure 5.1 below shows some potential planned and autonomous responses for human and natural systems. Planned responses are available for natural systems that are managed by humans (such as relieving existing stresses, species relocation, etc), but they have no intrinsic capacity to plan on their own.

Figure 5.1

CLASSES OF ADAPTIVE RESPONSE

		Planned	Autonomous
Natural		*(human intervention required)*	- Changes in growth period - Changes in species - Migration of ecosystem - Relocation of wetland
Human	Private	- Insurance - Raising houses - Managing natural systems	- Changes in farming - Air conditioning
	Public	- Early warning systems - Building codes, zoning laws - Relocation - Urban greening - Managing natural systems	- Water management - Raising dikes - Beach nourishment - Subsidies

Source: Adapted from N. Minmura 2004, *Past Findings and Future Discussions on Adaptation — Opportunities, Limitations and Barriers,* presented at PCC Expert Meeting on The Science Address UNFCCC Article 2 including Key Vulnerabilities.

Although humans will not have perfect foresight into the future and therefore will be required to autonomously adapt to the realised level of change, the ability to plan for adaptation critically distinguishes humans' ability to cope with change. By planning for change human systems have greater capacity, scope and ability to both minimise potential losses from change as well as maximise the potential gains.

Adaptation is ultimately about maximising welfare over time. In some situations this may mean that it is not optimal to invest in adaptive capacity ahead of change. In others it may mean that a sector or individual hedges their bets by investing in some additional capacity now, but then waits before committing additional resources to the problem. Inaction is also an adaptation strategy. It is synonymous with a strategy to 'wait and see' — gambling that lost time and opportunities to change systems now will not have overly costly consequences in the future. This is a vote of confidence in current coping capacities and the reactive adaptability of these systems. The decision to adapt need not be a once and for all, immutable decision; the optimal response may be a blend of responses — reviewed and revised periodically through time as more information and experience comes available.

The decision to invest in adaptive capacity requires a consideration of the costs and expected payoffs or benefits of a decision — and the time profile of those investment flows. Decision makers must decide between irreversible, short run investments in adaptive capacity, which one may or may not in the end require, and the potential long term benefits of that investment. The size of these benefits is dependent on the rate and character of climate change:

> Decisions with long payback periods or long term consequences (decades or greater) are vulnerable to assumptions regarding both short term variation and long term changes in future climate. Decision makers may underestimate the risk associated with climate variability and climate change. This may lead to choices that fail to deliver appropriate levels of adaptation. Alternatively, the climate risk may be overestimated, resulting in over adaptation and perhaps the unnecessary use of resources.[134]

[134] A.L. Hillman 2003, *Public Finance and Public Policy: Responsibilities and Limitations of Government,* Cambridge University Press: Cambridge.

The issues surrounding adaptation are not new to investors and every day decision makers. They are being confronted with a set of changes, the timing and nature of which cannot be clearly specified, that may have implications for them in the future. Action now can help position them for those changes — but if the move proves to be too early, there is a risk that action will be inappropriate or too costly.

Evaluating investments with uncertain pay–offs

Economics has spawned a healthy literature on these issues under the labels of 'decision making under uncertainty', and 'cost–benefit analysis'.[135] These subject areas deal with the optimal treatment of uncertain costs and benefits that are separated in time in order to maximise profits and/or welfare. A fundamental tenet of planning over an extended time horizon is that people and organisations have a preference for current consumption over delayed consumption.

Discounting

As illustrated in Box 5.1, this rate of time preference is reflected in the discount rate applied by individuals in thinking about investments and can be critical to the weightings they give to future costs and benefits. Importantly — even in the presence of fully functional finance markets and 'ruling' interest rates — difficulties in writing satisfactory contracts, absence of collateral, transaction costs, cash flow considerations and budget constraints can mean that subjective discount rates can be an important factor in investment decisions. These are applied everyday by private decision makers in managing their assets and assessing the investment options available to them. The same processes will apply to decisions on managing assets in a way that best takes account of the threat posed to those assets by climate change.

Dealing with risk and uncertainty

In parallel to developing appropriate relationships between future payoffs and short run costs through discounting, to understand the trade–off between benefits and costs across time we must also take account of attitudes to risk and uncertainty. These are closely related terms and often used interchangeably. But for precise analytical purposes *risk* is often specified as relating to probabilistic events (such as rolling dice) and choices relating to potential pay–offs with *known values and probabilities*. *Uncertainty* is a situation of 'compounded' risk where *neither the value of potential pay–offs or their probability is known*. Hollick notes an even more extreme situation where even the potential future outcomes are uncertain. He describes work in this area under the auspices of 'decision making under ignorance'[136]

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135 See for instance, C. Gollier 2001, *The Economics of Risk and Time*, MIT Press: Massachusetts; E.T. Copeland and J.F. Weston 1983, *Financial Theory and Corporate Policy,* 2nd Edition. Addison-Wesley Publishing: Massachusetts; and NSW Treasury 1997, Guidelines for Financial Appraisal, Paper TPP 97-4.

136 M. Hollick 1993, *An Introduction to Project Evaluation,* Longman Cheshire: Sydney, p 99 and pp 124-127.

Box 5.1

DISCOUNT RATES AND ADAPTATION INVESTMENT DECISIONS

Discounting is used as a tool for standardising costs and benefits that occur at different times. Casual empiricism highlights that people usually exhibit a preference for present benefits over deferred benefits. The strength of this preference (i.e. a choice to have $100 today rather than $110 next year) determines their subjective discount rate. Markets for borrowing (consumption now) and lending (consumption later) facilitate the interaction of these preferences and indicate a 'market' discount rate. Market rates can vary because they not only compensate lenders for deferred consumption — they also need to compensate the lender for the risk that the borrower might default and the loan will not be repaid. Rational decision makers considering an investment add up the costs and benefits after they have been adjusted for temporal differences to arrive at a net present value (NPV). Projects with positive NPVs offer a stream of benefits greater than the associated stream of costs.

First, there is the question of what is the appropriate discount rate. Generally corporate investments attract higher discount rates than prevail in the bond market, because of the greater default risks and potential variability in pay–offs involved. In terms of long run investments, few markets exist for assets with maturities exceeding 30 years; thus uncertainty complicates the long term valuation of benefits and costs. Typically, when evaluating long term public policy decisions, a social discount rate nearer to the government bond rate is employed to evaluate investment decisions.

The table below highlights the importance of selecting an appropriate discount rate by showing the NPV of an investment that yields a benefit of $1,000 at time *t*, where *t* can equal 10, 30, 50 or 100 years. As the table shows one percentage point movement in the discount rate can result in significant variations in valuations over time.

Selecting an inappropriate discount rate could result in an inappropriate valuation of an adaptation investment — which could lead to sub–optimal decisions by both private and public sector bodies. Attaching the right values to future outcomes is therefore obviously important.

Discount Rate	Investment horizon			
	10 years	30 years	50 years	100 years
0.02	$820	$552	$372	$138
0.05	$614	$231	$87	$8
0.10	$386	$57	$9	$0

Long term horizons' discount rates are also complicated by concerns for intergenerational equity. It has been argued that on an ethical basis, discount rates should be low — possibly zero — as there is no basis for valuing current generations more than posterity. But generally, arguments for the application of low 'social discount rates' are more applicable to long lived projects with strong social implications.

Economists are also investigating the time profile of the discount rate. Although conventional discounting approaches apply a single discount rate to the life of the project, some economists question this convention in the context of climate change, which is marked by profound uncertainty over long time horizons. This approach is appealing in its simplicity. However this will only be true if consumers have a common, constant, inter–temporal elasticity of substitution, and income growth is determined by a constant exogenous rate of technological progress. These conditions will vary over time, and is why discount rates vary in the short run. The trajectories of discount rates over time can have important implications for the 'pay–off' of long term investments.

Source: The Allen Consulting Group. For discussions of social discount rate issues, see Bureau of Transport and Regional Economics 2004, op. cit.; and R. Newell and W. Pizer W 2001, *Discounting the Benefits of Climate Change Mitigation: How Much Do Uncertain Rates Increase Valuations?,* prepared for the Pew Center on Global Climate Change: Arlington.

Economic and financial theories (backed up by observed behaviours) generally assume that investors are averse to risk. But it is also widely recognised that tolerance for risk can vary from individual–to–individual and be linked to the stakes involved, specifically the size of the potential loss relative to total levels of wealth and wellbeing. This is supported by psychological and experimental game theory observations.[137] It is also observable in day–to–day life: insurance markets operate to enable risk averse investors to hedge against the risk of costly future events. They do this by spreading the risk of those potential future costs across groups with a greater capacity (and/or willingness) to bear them — for a fee.

The decision to invest in adaptation is governed by the same principles. Decision makers must assess the expected future benefits and costs of investments in adaptive capacity, conditioned by their understanding of the risks involved and their tolerance for that risk. The availability and cost of insurance against climate risk will also be relevant to developing an adaptation strategy.

Vulnerability assessment does not need to await developments in climate science. System sensitivity to climate change and adaptive capacities and planned response options are equally important factors in assessing vulnerability. Early consideration of these elements will provide the maximum opportunity for a timely and effective response to climate change.

A variety of tools and techniques, ranging from qualitative analysis to sophisticated quantitative methods, are available to the decision maker to help analyse the risks that climate change might pose, and what to do about it. Table 5.1 provides an overview of some of these options.

Table 5.1

SELECT ANALYTICAL TECHNIQUES FOR DECISION MAKING UNDER UNCERTAINTY

Potential analytical techniques	Strategy description and uses
Consultation and cursory analysis	This strategy is based on a simple discussion of the issues. This is useful where there is high uncertainty — that is, where there is little known about the probability of an event occurring as well as the magnitude of its impact. It is a low cost entrée to more sophisticated empirical approaches.
Multi–criteria analysis	This approach supports decision making based on a mix of weighted qualitative and quantitative information (such as ‘balanced scorecard’ techniques). This strategy enables the investor to transparently assess the relative merits of alternative investment decisions and facilitates the comparison of outcomes in areas that are not immediately comparable — such as environmental or quality of life outcomes.
Scenario analysis	This methodology involves the development of scenarios, which project the implications of hypothetical future events and outcomes. For example, the IPCC SRES scenarios are a good example of potential scenarios that may be developed. The investor could then test the benefits and costs of the investment across the range of scenarios to understand the ‘fan’ of potential outcomes.
State–contingent and event tree analysis	This strategy is relevant to individuals seeking to identify a robust decision methodology under alternative ‘states of nature.’ A state of nature is a description of all the exogenous events relevant to the costs and benefits of a particular project. A full

[137] See UKCIP (R.I. Willows and R.K. Connell (eds)) 2003, *Climate Adaptation: Risk, Uncertainty and Decision making — UKCIP Technical Report*, UKCIP, Oxford; and A. Dixit and R.S. Pindyck 1994, *Investment Under Uncertainty,* Princeton University Press: Princeton N.J.

Potential analytical techniques	Strategy description and uses
	description of a state of nature may be complex, in which case an event tree, which describes a sequence of possible events over the life of the project, is useful.
Markov chain modelling	Markov chains can be applied to ‘event tree’ models to examine the propagation of uncertainty. There is a moderate to high data requirement.
Cost–benefit analysis	This strategy involves identifying and quantifying in monetary terms the potential benefits and costs associated with different decisions (including elements that may not typically have a market value, such as lifestyle qualities or health), and choosing the option that provides the largest net benefit. In this way it allows for a holistic evaluation of different investment–payoff combinations and consequences. This strategy requires an understanding of the probabilities and consequences of a decision and relies on the decision maker selecting an appropriate discount rate and assigning appropriate measures of value to all aspects of the decision.
Monte Carlo techniques	This is used to test the sensitivity of decisions and outcomes to changes in key parameters and variables.
Expected utility analysis	This approach, which can be traced back to von Neumann and Morgenstern, describes the expected payoffs as a function of the probability of an event occurring and the payoff associated with that event conditioned by the risk preferences of the investor. Hence for a risk averse individual the outcome of the risky event is explained by a concave utility function.

Source: J. von Neumann and O. Morgenstern 1944, *Theory of Games and Economic Behaviour*, Princeton University Press: Princeton; Bureau of Transport and Regional Economics 2004, op. cit.; and UKCIP.

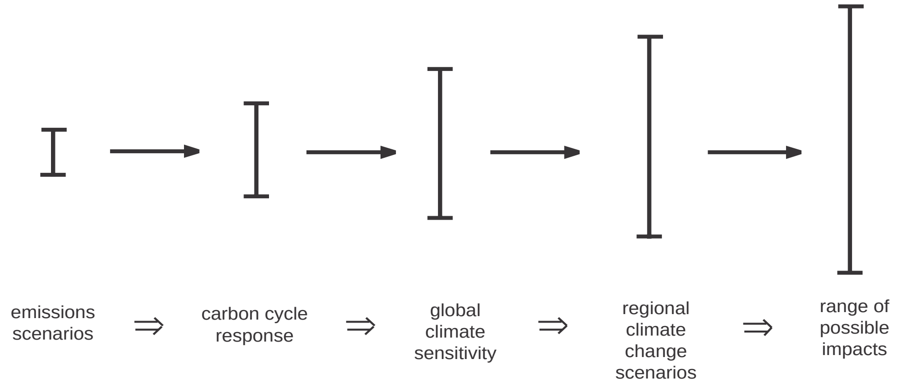
However, some of these tools have a high quantitative requirement and are most useful as aids to decision making that is informed by good information on the magnitude and probability of future events. Others have value in ‘testing’ different outcomes and implications and providing a basis for experimentation and scenario analysis.

The uncertainties associated with forecasting climate change can act as a significant impediment to adaptation action. They can also act as an impediment to even investing time and effort in the development of a cursory adaptation plan. This dynamic has emerged clearly from consultations with industry and policy stakeholders around the nation.

Figure 5.2 represents the uncertainties associated with formulating a climate adaptation response. This uncertainty begins with emissions projections which, at this point, do not allocate probabilities to climate change outcomes. There is also uncertainty in the carbon cycle response and global climate sensitivities — or how the earth’s systems will autonomously respond to increasing global CO_2 levels. This uncertainty is magnified when decision makers attempt to drill down to the regional level to determine climate changes and system responses.

Figure 5.2

CASCADE OF UNCERTAINTIES



Source: S. Schneider 2004, www.stephenschneider.stanford.edu.

Given the multiple levels of uncertainty that will need to be resolved, decision makers need to be careful in their assumptions and methodology as inappropriate discounting or misapplying decision techniques will result in poor outcomes such as:

- *under–adaptation* — when climate change factors are given insufficient weight in decision making;
- *over–adaptation* — when climate change factors are given too much weight; and
- *mal–adaptation* — when decisions are taken that make an activity or region more vulnerable to climate change.[138]

Unfortunately, as with many real world investment decisions, it is only after resources have been sunk into a project or process that planners have the opportunity to compare actual future outcomes with their best efforts at predicting them.

Flexibility and incrementalism can be important features of business planning under conditions of uncertainty. Dixit and Pindyck[139] point to the value of keeping options open. They demonstrate that bearing a higher short term cost (or tolerating uncertainty) is quite rational if such a course of action allows a large and irreversible investment to be delayed until a time when more is known about its long term pay–off or alternative investment opportunities. Pindyck[140] also observes that early action is rendered less risky if the irreversibility of costs is reduced. This points to the potential attractiveness of adaptation options that do not represent a dedicated investment in a possible climate outcome but have multiple applications or can be readily redeployed (or resold) if the climate threat does not eventuate. For example, it may be more attractive for a mining operation concerned about flooding to invest $100,000 in additional pumping equipment than to spend $80,000 on construction of a levy bank.

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[138] UKCIP 2003, op. cit., p 11.

[139] A. Dixit and S. Skeath 1999, *Games of Strategy,* W. W. Norton & Co: New York.

[140] R.S. Pindyck 2000, *Irreversibilities and the Timing of Environmental Policy,* FEEM Working Paper no.5: http://papers.ssrn.com/sol3/papers.cfm?abstract_id=229009

Human systems have demonstrated a significant ability to anticipate and react responsively to new challenges. Agencies such as the US National Academy of Science, and the United Nations Environment Programme (UNEP)[141] offer numerous examples of the ingenuity of mankind and the perseverance of individuals that has enabled productive activity to flourish in changing and potentially challenging environments. For example, Europe has already invested in understanding the optimal growing areas for different types of crops. Similarly, the UNEP has pointed out that water managers internationally have a 'wealth of knowledge and experience managing under different hydrological and socio–economic conditions. This places them in a good situation to be able to adapt the operations of their systems to climate change, if that change is not too great or too rapid.'[142]

Examples of adaptation and the ability of human systems to deal effectively with change also abound within Australia. Discussions with a variety of stakeholders have highlighted the capacity of Australian industries and communities to cope with variable climate conditions. In truth, it is seldom the case that 'ideal' conditions prevail or forecasts are completely fulfilled. Good managers build a degree of flexibility into their planning, and develop systems that are robust to unexpected and unwelcome developments.

Similarly, large and diversified systems can have a significant capacity to deal with change — provided they are not critically dependent on a vital and vulnerable element. Risk averse managers (and economic planners) will aim to encompass offsetting effects so that elements that are adversely affected by some changes will be matched by elements that benefit from them.

Changes in climate have been met with changes in practices and production systems — often at a modest incremental cost or inconvenience, and sometimes at a net benefit to those involved. Box 5.2 examines some examples of humans' ability to adapt and manage the natural environment in a way that has ensured continued productivity and prosperity.

However, there are other examples where human adaptation has not been so successful, with wrong choices being made in terms of the type, level and timing of responses.[143] In a world of risk and uncertainty, some investments will not pay–off, and it may not be possible to fully hedge against adverse future costs. Sometimes we can get it wrong. But when a risk is present, it is reasonable to look for low costs ways to avert it or reduce its costs for the future. Those that take out house or car insurance buy peace of mind — it would miss the point to consider those who pay their premiums but do not have a major accident that year as having made a poor investment. Adaptation planners must look forward into an uncertain future and seldom get the chance to change their choices and investment decisions retrospectively.

141 See National Academy of Science 1992, *Policy Implications of Greenhouse Warming,* National Academy Press: Washington D.C.; I.M. Goklany 1995, *Strategies to enhance adaptability: Technological change, sustainable growth and free trade,* Climatic Change, vol 30, pp 427-449; J.F. Feenstra et al 2003, op. cit.; W.E. Easterling, B.H. Hurd and J.B. Smith 2004, *Coping with Global Climate Change: The Role of Adaptation in the United States,* Pew Center on Global Climate Change: Arlington.

142 J. F. Feenstra et al 2003, op. cit., Sections 6 and 8.

143 W.E. Easterling, B.H. Hurd and J.B. Smith 2004, op.cit.; and I. Burton, R.W. Kates and G.F. White 1993, *The Environment As Hazard,* Second Edition, Guilford Press: New York.

Box 5.2

ADAPTATION AND HUMAN SYSTEMS

Change location: The translocation of winter wheat in the US

By 1999, the winter wheat production boundary was extended north to areas that were approximately 4.5°C cooler and 20 per cent drier than the region where winter wheat was grown in 1920. This expansion of the winter wheat farming zone was the result of innovation in historic farming practices and innovative crop breeding.

Prevent the threat: The drying of Southwest Australia

As discussed in the previous chapters, the southwest of Australia has arguably already experienced the effects of climate change, manifest in a 10 to 20 per cent sustained fall in precipitation for the area since the 1970s. Following a review[144] the Water Authority of Western Australia invested in incremental water system adjustments, including the earlier development of water sources and promotion of demand side management. It also invested additional funds into research and the ultimate establishment of the Indian Ocean Climate Initiative, a body charged with the continuing investigation into the reasons for declining rainfall and precipitation forecasting for the area.

Educate, inform and encourage behavioural change: Eutrophication in Australia

A number of programs have been initiated in Australia aimed at managing existing problems arising from poor land use practices, such as soil erosion, salinity and eutrophication — the process by which a body of water becomes enriched in dissolved nutrients that stimulate the growth of aquatic plant life. These programs are highly relevant to managing climate change — especially the possibility of maladaptation — as knowledge gaps were identified as critical barriers to understanding the potential impacts of change and in turn developing appropriate adaptation strategies. An example provided by the AGO is the National Eutrophication Management Programme (NEMP), which seeks to understand the causes of algal blooms. Algal blooms are estimated to impose a cost of $200 million on Australian industries and governments, and the work of NEMP is used to help educate industry about how to mitigate eutrophication.

Sources: Easterling 2004, op. cit.; and B. Pittock (ed) 2003, op, cit., pp 163–164.

It remains for the decision maker to develop strategies that give the best chance of protecting or maximising their key objectives. Possible constructs drawn from the economics literature include:

- maximising minimum gains;
- minimising maximum losses;
- minimising the maximum cost of choosing the wrong alternative (minimax regret);
- applying weightings to maximum and minimum losses (Hurwicz criterion); and
- choosing on the basis of robustness (selecting options that provide a ‘reasonable’ pay–off under a variety of possible outcomes).[145]

Observed behaviours — evidence from the insurance industry

However, while a variety of sophisticated planning tools and analytical techniques are available to decision makers, it is apparent that individuals and firms do not always behave as theory suggests. Recent experience also points to a growing concern within established markets that climate change will stretch existing capacities for dealing with risk.

[144] B.S. Sadler, G.W. Mauger and R.A. Stokes 1988, *The Water Resource Implications of a Drying Climate in South-West Western Australia,* Greenhouse: Planning for Climate Change, CSIRO.

[145] See UKCIP 2003, op. cit.; and Hollick 1993, op. cit.

Consumer behaviour

Evidence from the United States suggests that consumers often fail to adopt even low cost protections against climate hazards, and despite general risk aversion, accept risky gambles rather than harden their premises against climate events.

A report by the Wharton Center for Risk Management and Decision Processes cites major surveys of residents in hurricane and earthquake prone areas of the USA that found that, in a majority of cases, no special efforts had been made to protect their homes:

> A July 1994 telephone survey of 1,241 hurricane zone residents by the Insurance Institute for Property Loss Reduction revealed that 62 per cent of respondents indicated they had not installed hurricane shutters, used laminated glass in windows, installed roof bracing, or made sure that side walls were bolted to the foundation either before or after Hurricane Andrew (which occurred in 1992).
>
> Residents in earthquake areas are also not adopting such simple mitigation measures as securing their gas water heaters with plumber's tape — a mitigation measure that costs less than $5 in materials and one hour of labor. A 1989 survey of 3,500 homeowners in four quake–prone California counties reported that only between five and nine per cent of the respondents had adopted any loss reduction measures.[146]

Further, as in the area of energy efficiency, the study found that participants exhibited a strong inclination to disregard benefits beyond about three to five years, and assessed returns on investments in risk mitigation measures over that period. As noted by the study,

> Many people who live 'payday to payday' are not inclined to invest in protective measures for future disasters that, they believe, many never happen to them.[147]

While a wide range of factors can help explain this behaviour, the issues of belief and 'motivation to action' can have particular resonance in consideration of climate change adaptation. Psychology recognises that individuals can exhibit a preference for particular belief sets and be resistant to information that does not accord with their preferred views and outcomes. This common human characteristic is known as 'cognitive dissonance' and can result in a reluctance to accept and act on advice that suggests that there is a threat, or that current plans and investment decisions need to be revised. The economic consequences of this phenomenon are considered in a seminal article by Akerlof & Dickens in 1982.[148] One simple implication is that a concerted and consistent effort may be required to convince an inherently sceptical constituency of the need for action now to avoid possible costs in the future.

Market capacity

There is growing concern in Australia and overseas that climate change may require a re–think of existing actuarial assessments of storm risk, and force insurance providers to revise their pricing and coverage policies. The capacity of the industry to sufficiently spread these risks across existing market structures is also being questioned by some analysts.

A US Natural Disaster Forum held in December 1997, with more than 100 participants from academia, Wall Street and Federal, State and local government raised the prospect that the

146 P.R. Kleindorfer and H. Kunreuther 2000, *Managing Catastrophe Risk,* Regulation, 23(4). pp 26-31.

147 Ibid, p 27.

148 G.A. Akerlof and W.T. Dickens 1982, *The Economic Consequences of Cognitive Dissonance*, American Economic Review, June pp 307-19.

‘… financial capacity of the insurance industry is inadequate to cope with a ‘megadisaster’ such as a repeat of the 1906 San Francisco earthquake (estimates losses of US$100 billion) or even a major East Coast hurricane (estimated losses of US$75 billion).’[149]

The events in Florida in recent months, in the form of hurricanes Frances, Charley, Ivan and Jeanne, will reportedly strain but not break US insurers, with an estimated combined damage bill of US$20 billion.

The risk of a potential collapse in insurance markets have also been echoed more recently in Europe where a range of natural disasters, and added risks from terrorism, have spurred further reassessment of risks among investors, and the potential role of government in supporting this market.[150]

Within Australia, Tony Coleman, chief actuary of the Insurance Australia Group warns:

> … $1,500 billion of Australia’s wealth is locked up in homes, commercial buildings, ports and other physical assets. This is equivalent to nine times the current national budget or twice our gross domestic product. The insurance industry currently underwrites the risk to a significant proportion of these assets from weather events but climate change threatens its ability to do so as effectively in the future. Therefore the effect on Australia from climate change is quickly becoming a social, economic and political issue.
>
> The insurance industry in Australia, like many other countries, is also vulnerable to other catastrophic events occurring worldwide through its interconnection with reinsurance. Both natural and manmade disasters trigger a sequence of financial events for insurers and reinsurers. Large and unanticipated losses lead to large insurance payouts, which reduce insurers’ and reinsurers’ capital reserves and heighten their uncertainty about losses from future events. As the supply of reinsurance dwindles, sometimes simultaneously with an increase in demand, prices climb.[151]

These developments point to an additional layer of issues that need to be taken into account in forward planning on adaptation. Investors need to think not only about the actions they can take within their own resources to harden or adjust their systems in anticipation of climate change, but also recognise that climate stresses can also affect the systems around them. The pressures of climate change will test the performance of existing assets and market relationships.

5.2 A role for government

Government is generally ascribed with three important economic functions within a market–based economy, these are:

- *allocation* — supporting the allocation of resources and the operation of markets and production activities in a way that maximises benefits to society as a whole;
- *distribution* — distributing costs and benefits within society in a way that accords with equity objectives; and

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149 Public Private Partnership 2000, *The Uncertainties of Managing Catastrophic Risk*, Report on Second Forum, 11 December 1997.

150 See M. Nell and A. Richter 2004, *Catastrophe Events as Threats to Society: Private and Public Risk Management Strategies*, Working Papers on Risk and Insurance, No. 12, January, Hamburg University.

151 T. Coleman 2003, *The Impact of Climate Change on Insurance against Catastrophes*, presentation to the Institute of Actuaries Australia 2003 Biennial Convention.

- *stabilisation* — intervening in the market economy to diminish shocks and volatility, to facilitate planning and investment, and to support ongoing improvement in wealth and living standards.[152]

All of these functions are in some way connected to greenhouse policy development through their relevance to issues such as environmental spillovers, intergenerational equity, the fair distribution of greenhouse costs and benefits within the current society and the need for an effective, long term and internationally attuned approach.

A set of important issues and actions can be identified within these functions that have strong implications for government's role in facilitating an efficient climate change adaptation response within Australia.

At the same time it is important to remember that a nation is more than its economy and Government's responsibilities extend beyond its economic functions. Governments have important social and environmental objectives that will be affected by climate change and will condition its response to the impacts of climate change.

These matters are discussed below in the context of key action areas.

Leadership

Government has a significant, ongoing role to play in supporting the efficient operation of markets and ensuring that appropriate incentives are in place to drive necessary adjustments within the economy. As highlighted in the previous section, efficient adaptation will involve making good assessments of climate risks and ensuring that systems are geared to respond flexibly to the challenges (and opportunities) that climate variability will increasingly generate in the future. At this point, the implications of climate change for different regions are far from certain, and attitudes and potentials for dealing with this uncertainty, and indeed climate change itself, vary. Even if it were possible, it would be inappropriate for policy makers to try to enforce particular behaviours on private decision makers through a paternalistic one–size–fits–all approach.

As illustrated in Table 5.2 around 75 per cent of Australia's economic wealth and asset base is in private hands, and owners have strong incentives to protect it. Governments should work within this framework to harness these incentives, and ensure they lead to outcomes that promote:

- efficient use of scarce resources;
- flexibility and mobility;
- forward looking behaviour; and
- responsiveness to changing economic conditions.

[152] See C.V. Brown and P.M. Jackson 1982, *Public Sector Economics*, second edition, Martin Robertson & Company: Oxford; and R.A. Musgrave and P.B. Musgrave 1982, Public Finance in Theory and Practice, 3rd edn, McGraw Hill, Sydney.

Table 5.2

OWNERSHIP OF AUSTRALIA'S NET CAPITAL STOCK, AT JUNE 2003

Sector	Value ($m)	Share (%)
Financial corporations	7 223	3.6
Non–financial corporations	768 106	38.2
Households & other enterprises	880 954	43.8
General government	289 641	14.4
Total	**2 010 924**	**100.0**

Source: ABS Cat. 5204.0, Australian National Accounts, Table 70, Capital stock by institutional sector.

These are key elements of Australia's microeconomic reform agenda. These outcomes will help sharpen adaptation incentives and actions on an economy–wide basis. They can also take on particular importance for some climate–critical activities and industries.

Information provision and standard setting

Governments have a key role in facilitating market operations through the provision of information and standard setting. These activities can prevent wasteful duplication of effort and provide a solid basis for planning, negotiation and system compatibility.[153] Timely and authoritative information on climate change is a critical, ongoing requirement for efficient adaptation planning.

Similarly, there is a variety of standard setting and advisory bodies whose codes and recommendations can have significant implications for climate planning and the capacity of long lived structures and settlements to cope with future climate events. Such agencies include the:

- Australian Building Codes Board;
- Institute of Engineers Australia; and
- Australian National Committee on Large Dams.

A range of planning and zoning functions are also carried out at State and local government levels (see Appendix B). The perspectives and advice of bodies such as the Bureau of Meteorology can be vital input to the deliberations of these groups.

[153] Bureau of Industry Economics (BIE) 1994, *Energy Labelling and Standards,* AGPS: Canberra.

Recognition of external costs

Efficient market outcomes also require that costs (or benefits) impacting on third parties are reflected in decision making. If this is not the case then the activities producing these 'spillovers' will be over (or under) provided. In the case of adaptation to climate change this efficiency requirement can have relevance to the status of public liability and safety provisions applied under the law. It would be necessary to examine the robustness of these provisions to ensure that they are sufficient to provide adequate incentives to commercial operators and property owners to take into account the wider spillover ramifications of failing to take reasonable precautions against the adverse impact of climate change on their systems. This issue has been raised by the Queensland Division of the Planning Institute of Australia in a recent issues paper focusing on local government liabilities and by Gans & King (2004) with respect to infrastructure.[154] It is feasible that this issue could apply more widely.

Partnership

The responsibilities of government in regulating and addressing deficiencies in markets cannot be separated from the need to work with private participants to better understand their needs. An ongoing dialogue with stakeholders is essential to understanding needs and issues 'at the coal face', and formulating an effective response. Work undertaken in this consultancy has highlighted a need for more and better information on likely future climate change. But it has also highlighted a patchy understanding and acceptance of future climate risks. Motivation to act is currently low in many cases — particularly beyond the realm of government agencies. This suggests a need for simple tools — tailored to private sector needs — that can aid in assessing climate change vulnerability, and for government action — guided by private sector input — to address strategic issues.

Development of a vulnerability toolkit

As highlighted previously, the task of vulnerability analysis can be broken down into components of:

- *exposure* — the climate changes that will affect the system;
- *sensitivity* — the reaction of the current system to those changes; and
- *adaptive capacity* — the scope for modifying the system to increase its capacity to cope with changes in climate conditions.

While these elements combine together to produce a net climate 'vulnerability', it is possible to separate them and analyse them individually as part of a planning exercise. Greater detail on the climate threat need not precede a process of system evaluation. In essence, each of these elements lends itself to a stream of research and planning activity, with appropriate interaction between them. This dynamic is illustrated in Figure 5.3. Information on the vectors (i.e. relevant physical manifestations — temperature, precipitation, storm activity, sea level rises) of climate change is now sufficiently advanced — even at a regional level — that asset owners can begin evaluating the capacity of their systems to deal with these pressures and, if necessary, develop options for enhancing this capacity or withdrawing from the threat.

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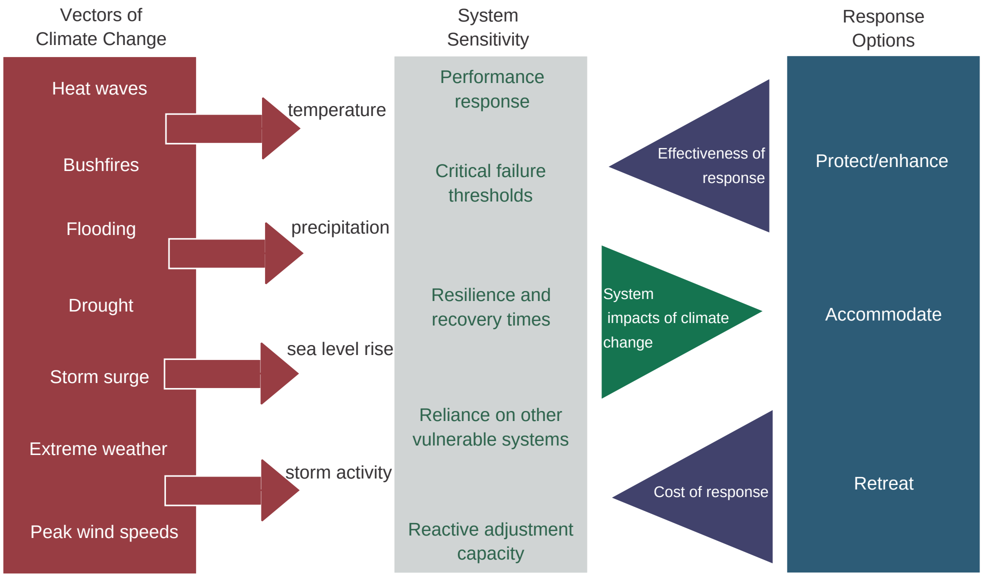
154 Planning Institute of Australia Queensland Division 2004, *Sustainable Regional and Urban Communities Adapting to Climate Change – Issues Paper,* PIA, June; and J.S. Gans and S.P. King 2004, *Taking into Account Extraordinary Circumstances in Regulatory Pricing,* August, Business School: Melbourne.

Figure 5.3

A SYSTEMS CHECK FOR RISK AND VULNERABILITY



Source: The Allen Consulting Group

The key questions for asset owners and business operators are, 'How well is my current system configuration and set of business–as–usual procedures likely to deal with potential climatic changes?' and 'What are my best options for dealing with the climate threat in those areas where my coping capacity is low?'

For most human systems, trends in climate changes over the next few decades are likely to be readily accommodated within the normal maintenance or upgrade procedures currently in place. They will represent marginal year–on–year changes — although for some operators already under pressure and pushed to the limits of their viability this may mean things will get marginally better or marginally worse.

However, the climate variability and extreme weather events that are likely to be a feature of climate change can significantly test human systems and signal a need to begin building coping capacities in advance of these events, through increased structural engineering standards and/or extending reactive capabilities.

The weighting and mix of these issues will differ across systems, and need to be assessed by the owners themselves. It would be appropriate for government to facilitate this process through development of a decision tool that helped identify the climate sensitivity of a system. A generic form of such a tool would qualitatively address:

- vectors of climate change (*i.e. 'what climate effects are likely to change?'*);
- links between system performance and vector variability or extremes *('how important are these things to me now?'*);
- feasible percentage changes in current vector magnitudes and variability conditions that might be observed within a reasonable future timeframe — such as 5, 10, 25 and 50 year horizons (*'what would foreshadowed differences in these climate effects imply?'*); and
- scheduled opportunities for major upgrades (*how might I best prepare for these changes?*).

Such a tool could focus thinking on the major parameters of a climate change 'risk assessment', and help identify the problem. Subsequent thinking on costs and investment in response options would involve deeper analysis on a project specific basis, and the particular attitudes and circumstances of individual operators (as outlined earlier in this chapter).

While such an approach can help asset owners perform a stocktake of their own systems' sensitivity to direct climatic influences, it would need to be supplemented by further information on the climate sensitivity of systems outside their control. The potential domino effect of system failures and load shifting is a well known phenomenon in many extreme situations. This points to the need for supporting macro vulnerability assessments comprising case studies and joint stakeholder analysis.

Research and development

Support for research and development is an established function of government, primarily associated with the strong potential spin off benefits of new knowledge creation and dissemination, and the difficulties of internalising all benefits from such activity through the patent system.

Some preparations for climate change will involve technological solutions requiring long lead times and can be relevant to dispersed industry stakeholders. This is particularly the case for agricultural producers. A range of rural R&D corporations have been established to address the production technology needs for a range of agriculture activities. These agencies can play an important role in assisting the adaptation response and flexibility of agricultural producers through development of drought and heat tolerant cultivars and improved production methods. This activity should be guided by the changes suggested by climate science and the needs and perspectives of industry stakeholders.

Macro level economic and systems research can also be a function falling to government. Many individuals and activities can have a stake in this proceeding but are not in a position to coordinate effectively with each other to bring this about. This is a strategic function that addresses the role of individual actors and the implications of their interaction. A range of high level and background issues are relevant to the implications of future climate change on Australia including:

- better understanding of the climate system and how it is likely to change as a result of greenhouse forcing and other anthropogenic factors;
- better understanding of how changed climate will affect biophysical, social and economic systems;
- economic impacts of climate change on Australia, set against impacts on supply and demand in key markets overseas;
- demographic changes and their implications for health, labour supply and internal migration; and
- implications for foreign aid and socio–political pressures overseas, particularly in the Asia Pacific region.

Examine needs of insurance markets

Climate change pressures, particularly the threat of increases in the severity and frequency of extreme events, can test the ability of insurance markets to absorb the cost of such events. A potential outcome of these pressures is an increase in the cost of insurance cover, higher excesses and withdrawal of coverage in some areas. Insurance against flooding is commonly excluded from many policies, and protection against storm surges and landslip can also be absent.[155]

The risks associated with climate can fundamentally affect costs within the insurance industry and its ability to spread its exposure to climate–induced losses. There is a potential role for government in exploring options, in conjunction with the insurance and wider finance industry; for reducing and spreading risk exposures; and promoting incentives for household hazard reduction.

Options proposed for consideration in the US include:

- tightening of local building codes;
- providing seals of approval for high standard constructions (endorsed by finance providers and the building industry);
- linking bank loans with insurance (and investment in hazard reduction);
- providing lower deductibles (insurance 'excesses') linked to hazard reduction; and
- broadening protection against catastrophic losses (by broadening access to capital markets).[156]

Governments have an incentive to encourage privatisation of risk and reduction in the amount of uninsured losses. Such losses, particularly when incurred on a large scale, can be a source of budget pressure.

Ownership

Asset and infrastructure management

In addition to actions needed to facilitate efficient decision making and adaptation in the private sector, it also falls to government to ensure that its own house is in order with respect to considering and guarding against climate risk. Government is a major owner and regulator of infrastructure within Australia, and a significant asset holder.

All governments have a major controlling interest in a variety of major business operations spanning transport, telecommunications, electricity and water. Similarly, local governments control and have responsibility for significant infrastructure investments[157]:

> Local government infrastructure is valued at more than $150 billion. Of this, $110 billion comprises built infrastructure, plant and equipment. Roads, bridges and related assets are the largest single component, worth around $75 billion. A great deal of this infrastructure dates from the post–war period and was built in the Fifties and Sixties with the help of state or federal funds. These assets are now reaching the end of their useful life and are in need of replacement or renewal.[158]

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155 Insurance Council of Australia (n.d.), *Flood Insurance Are You Covered?,* available at www.ica.com.au

156 Kleindorfer & Kunreuther 2000, op. cit., pp 29-31.

157 M. Montgomery 2004, *The Mounting Infrastructure Challenge Facing Local Government,* address to National Infrastructure Summit: Melbourne, 16 August.

158 Mike Montgomery, President Australian Local Government Association, August 2004.

It will fall to governments to ensure that these assets are appropriately managed in accordance with the potential threat posed to them by climate change, and with due consideration of the costs to the community that would be incurred if the services they provide were disrupted. The process of vulnerability assessment has commenced in some areas, but there is scope for this to proceed on a more systematic and priority–driven basis.[159]

Stewardship

Governments also have a clear role in protecting community interests and assets for which market valuations do not exist, but are nevertheless widely considered as making an important contribution to community wellbeing.

Facilitating the adaptive response of threatened species and ecosystems

As highlighted previously, natural systems have no ability to plan for climate change and are solely reliant on their natural adaptive capability. For species that come under significant pressure from climate change this is unlikely to be sufficient to ensure their survival. Localised pressures may result in the loss of species in some areas and the prosperity of others. This natural selection process, driven by climate change, can be expected to reduce biodiversity overall and could significantly degrade some biologically important and economically valuable ecosystems.

Government has a clear role in investigating the implications of climate change for important species and ecosystems, and in developing options for supplementing their natural adaptive response. The National Biodiversity and Climate Change Action Plan is being implemented in each jurisdiction and will result in an informed and integrated approach to reducing the negative impact of climate change on Australia's unique biodiversity.

Regional adjustment and disaster relief

Climate change can threaten the livelihood of regional communities through its impact on climate–vulnerable industries. Policy makers will need to consider the prospect of these 'structural changes' affecting the competitiveness of regional industries. While regional communities tend to exhibit a high degree of mobility and acceptance of the variables that can affect their industries, government programs that aim to protect against climate 'shocks' can impede efficient adjustment when these shocks are in fact a symptom of more fundamental changes. They need to guard against this risk.

The capacity of communities to cope with extreme climate events needs to be considered and coordinated at government level. Emergency planning and response capacity has tended to ratchet upward to reflect the impact of past events that have tested the system. Such planning should take into account the implications of climatic changes that could imply more frequent and severe storms in some regions. Storms and other extreme events, such as heat waves, can also test emergency health services and other medical facilities.

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[159] See Austroads 2004, *Impact of Climate Change on Road Performance,* Austroads Publication No. AP–R243/04, Austroads: Sydney.

5.3 Implications for existing Australian Government measures

As noted above, all levels of government, industry and communities have a role in responding to the impacts of climate change. State and Territory Governments have substantial responsibilities that will be affected by climate change impacts. This section of the report, however, is explicitly aimed at identifying risks to the Australian Government that arise from the impacts of climate change.

A wide range of existing Australian Government initiatives stand to be affected by climate change. Managers of these programs will need to take these growing climate pressures into account in future planning around program risks, scope, priorities and resources.

Table 5.3 outlines a number of key Australian Government policies and programs whose goals and performance could be significantly affected by climate change and adaptation needs, and which should take close account of climate change risks in their planning and design processes.

At the Australian Government level, greenhouse impacts and adaptation needs cut across a wide range of activities and portfolios. Relevant agencies include:

- Department of Agriculture, Fisheries and Forestry;
- Department of the Environment and Heritage;
- Department of Industry, Tourism and Resources;
- Department of Transport and Regional Services;
- Department of Health and Ageing;
- Department of Foreign Affairs and Trade;
- AusAID;
- Department of Education, Science and Technology;
- CSIRO; and
- Department of Prime Minister and Cabinet.

Table 5.3

AUSTRALIAN GOVERNMENT PROGRAMS IMPACTED BY CLIMATE CHANGE PRESSURES

Portfolio	Sector interest	Policies – Key strategies	Relevance of climate change
Department of Agriculture, Fisheries and Forestry	Sustainable agricultural production	**Agriculture – Advancing Australia** (AAA) is a package of Australian Government programmes designed to help primary producers in agriculture, fishing, forestry and processed food industries become more competitive, sustainable and profitable.	A number of possible climate change scenarios (particularly reduced rainfall in southern states) may affect the profitability of many primary producers.
	Drought relief	**Australian Government Drought Assistance** programmes are lending practical support to drought affected farmers and rural communities through employment services, free personal and financial counselling, income support and interest rate relief.	The effects of climate change scenarios on climate variability, including drought, warrant further investigation.
	Research and development	**Research and development corporations** invest in rural R&D with the aim of achieving better productivity, sustainability and the delivery of high quality products which underpins the competitiveness and profitability of Australia's agriculture, fish and forestry industries. Australian Government contribution was over $200m in 2003-04.	Rural R&D corporations are able to commission and disseminate research to assist primary producers adapt to the impacts of climate change.
	National Landcare Program	The goal of the **National Landcare Program** (NLP) is to increase the profitability, competitiveness and sustainability of Australian primary industries through improved management of natural resources. The programme provides support to the Landcare movement for on-ground projects. The NLP encourages landholders to undertake Landcare and related conservation works by supporting collective action by communities to manage the environment and natural resources sustainably.	Most of the activities conducted under the NLP would have a greenhouse mitigation or adaptation to climate change benefit.
	Forestry industry policies	The Australian Government, State and Territory governments are all signatories to the 1992 **National Forest Policy Statement** (NFPS). The NFPS provides the framework within which the governments can achieve cooperatively their vision for sustainable management of Australia's forests and ensure the community obtains a balanced return from all forest uses. A key element of the approach adopted in the National Forest Policy Statement involves Regional Forest Agreements (RFAs) between the Australian Government and State governments. Regional Forest Agreements provide secure access to wood resources and help to create a positive environment for investment in value–adding manufacturing.	Climate change may affect the productivity of forest plantations as well as the productivity and species composition of native forests.
	Sustainable fisheries	The **Australian Fisheries Management Authority** (AFMA) is the statutory authority responsible for the efficient management of Australian Government fishery resources. AFMA licenses Australian vessels for operation on the high seas and manages fisheries out to the 200 nautical mile Australian Fishing Zone (AFZ) and, in some cases, by agreement with the States, to the low water mark. AFMA provides management, advisory, compliance and licensing services and implements appropriate fisheries management arrangements.	Rising sea temperatures are likely to affect the distribution of fish species and could impact on sustainable fishery resources.

	Salinity and Water	The Australian Government and State/Territory Governments are implementing strategic, national and coordinated approaches to the nation's environmental issues through the **National Action Plan for Salinity and Water Quality** (NAP) and the **Natural Heritage Trust** (NHT). These programs are jointly delivered through the Department of Agriculture, Fisheries and Forestry and the Department of the Environment and Heritage (DEH). Further details of the programs are listed under the DEH section.	
	Murray-Darling Basin Initiative	The **Murray–Darling Basin Initiative** is the partnership between governments and the community to give effect to the 1992 Murray–Darling Basin Agreement. The purpose of the Agreement (Clause 1) is 'to promote and co–ordinate effective planning and management for the equitable, efficient and sustainable use of the water, land and other environmental resources of the Murray–Darling Basin'. The Initiative is the largest integrated catchment management program in the world, covering the watersheds of the Murray and Darling rivers, an area of over one million square kilometres.	Stream flows Murray–Darling could be reduced by up to twenty per cent by 2030.
	Biosecurity	**Biosecurity Australia** provides science based quarantine assessments and policy advice that protects Australia's favourable pest and disease status and enhances Australia's access to international animal and plant related markets. **The Australian Quarantine and Inspection Service** (AQIS) is Australia's first line of defence, protecting our unique environment against exotic pests and diseases. AQIS inspects incoming luggage, cargo, mail, animals and plants and their products, and provide inspection and certification for a range of exports.	Climate change is likely to affect the range and distribution of pests and weeds, with potentially important implications for quarantine decisions.
Department of Industry, Tourism and Resources	Tourism	The **Tourism White Paper Implementation Plan** 2004 has been developed in consultation with key tourism industry stakeholders, Australian Government Departments and state and territory governments. The Plan outlines how, working in partnerships, governments and industry will further implement the Tourism White Paper initiatives including structural reform and initiatives including a $24m program for tourism development as well as developing tourism and conservation partnerships	A great deal of tourism in Australia centres on natural attractions such as the Great Barrier Reef, Kakadu and Alpine regions that are threatened by climate change. The Great Barrier Reef is an important attractor of international tourists.
	Energy	The Government's White Paper, **Securing Australia's Energy Future** supports developing the Government's energy policy agenda through economic research, data compilation and forecasting, understanding the impact of R&D and new technologies, and providing policy advice on energy efficiency.	Climate change is likely to affect demand for energy and the vulnerability of the energy transmission network.
	Business investment	**Invest Australia** is Australia's national inward investment agency, set up by the Australian Government in 1997. Investment in Australian industries is promoted through attracting foreign investment and facilitating investment projects. Investments in aquaculture, dairy, forestry, horticulture, meat and wine industries are promoted and assisted by industry specialists.	Some industries may benefit from investments taking into account the anticipated change in climate. Attracting foreign investment in some industries may require knowledge of the impact of climate change on different industries.

	Building industry	The Department of Industry, Tourism and Resources operates a number of programs designed to improve the efficiency and competitiveness of Australian industry, including the Building and Construction Action Agenda, Building Codes and the Business Builders Program, Australian Industry Participation Framework and the Heavy Engineering and Infrastructure Action agenda.	Australian residential and commercial buildings are vulnerable to the impacts of climate change, including possible changes in wind speed, temperatures, flood, drought, bushfire and extreme weather events.
Department of Prime Minister and Cabinet	Water	The Council of Australian Governments (COAG) has developed a **National Water Initiative** (NWI) which will: · Improve investor confidence through more secure water access entitlements; · Expand permanent water trade for more profitable use of water; · Ensure ecosystem health; and · Encourage water conservation in our cities.	Reduced run–off in Southern Australia and increased temperatures will have important implications for the availability of water.
Department of Transport and Regional Services	Support for regional communities	**The Sustainable Regions Programme** is the major initiative under the **Stronger Regions, A Stronger Australia Framework**. The Programme assists regional communities to address priority issues they have themselves identified and offers a planned, integrated approach to regions facing economic, social and environmental change. Assistance under the programme will initially be provided to eight 'prototype' regions. $32.5m over 4 years. The **Regional Partnerships Programme** ($308.2m over 4 years) supports: • strengthening growth and social and economic opportunities in regional communities; • improving access to services with priority to communities in regional Australia with a population of less than 5,000; • planning by investing in projects that assist communities to identify and explore opportunities and to develop strategies for action; and • assisting in structural adjustment by investing in projects that assist specifically identified communities and regions adjust to major economic, social and/or environmental change.	A number of regions have been identified as vulnerable to climate change. The ‘sustainability’ of these regions could be affected by climate change impacts. Considering the effect that the collapse of the tourist industry would have on the Cairns–Great Barrier Reef is a good illustration of the possible magnitude of these effects.
	Natural disaster management	The COAG Review of natural disaster and mitigation arrangements recommended a shift beyond disaster response and reaction, towards anticipation and mitigation. In response, the Australian Government announced in the 2003–2004 Budget funding for a new **Natural Disaster Mitigation Programme** (NDMP). The NDMP funds a range of measures including natural disaster risk management studies, mitigation works, measures and other related activities that contribute to safer, sustainable communities better able to withstand the effects of natural disasters. **Natural Disaster Relief Arrangements** (NDRA) apply to natural hazards such as bushfire; earthquake; flood; storm; cyclone; storm surges; landslide; tsunami; meteorite strike; or tornado. Eligible relief measures provided by the States and Territories that qualify for Australian Government assistance under the NDRA include:	Floods, cyclones, storm surges, bushfires are all likely to increase in frequency and intensity due to climate change. This has implications for the cost to the Australian Government of assistance with natural disaster management, the implementation of disaster mitigation projects, and planning for responses to natural disasters.

		• grants for relief of 'personal hardship and distress'; • concessional interest rate loans to farmers, small business operators and voluntary non–profit bodies to replace assets that have been significantly damaged in an eligible disaster; • payments to restore or replace essential public assets; and • payments for providing psychological counselling. The **Regional Flood Mitigation Programme** is an Australian Government initiative working in partnership with State, Territory and Local Governments to implement priority, cost effective flood mitigation works and measures in rural, regional and outer metropolitan Australia.	
	Road, rail, air infrastructure security	**Auslink** is an $11.4 billion investment over 5 years in road and rail infrastructure projects. The Australian Government is responsible for airports.	The possible Australian Government contribution to costs of increased transport infrastructure maintenance needs to be considered.
Department of the Environment and Heritage	Biodiversity and environment protection	The ***Environment Protection and Biodiversity Conservation Act 1999*** (EPBC Act), protects matters of national enviromental significance (threatened species and communities, migratory species, world heritage areas, Ramsar wetlands, the Commonwealth marine area, national heritage places, nuclear actions) from significant impacts. It protects the environment on Commonwealth land. The EBPC Act regulates wildlife trade and requires permits for activities that affect listed species or communities in Commonwealth areas; cetaceans in Commonwealth waters and outside Australian waters. It also provides for identification of key threatening processes, protection of critical habitat, preparation of management plans, threat abatement plans and recovery plans, and issuing of convervation orders.	Biodiversity is highly vulnerable to the impacts of climate change.
	Parks and the National Reserve System	The Australian Government, through the Director of National Parks, manages Commonwealth parks and reserves. Twenty-one reserves are currently declared under the EPBC Act, comprising 6 Commonwealth National Parks, 13 Commonwealth Marine Protected Areas, 2 Botanic Gardens. The National Reserve System aims to establish and manage, in partnership with states and territories, the private sector and Indigenous communities, a comprehensive, adequate and representative system of reserves.	Climate change is likely to have implications for Parks and the National Reserve System, particularly if it results in changes in species ranges.
	Water, natural resource management	The **National Action Plan for Salinity and Water Quality (NAP)** tackles two major natural resource management issues facing Australia's rural industries, regional communities and our unique environment. Australian and State and Territory Governments work with people in communities to find local solutions for local problems. It is jointly administered by the Australian Government departments of Agriculture, Fisheries and Forestry and the Environment and Heritage, and is delivered in conjunction with the National Heritage Trust.	Water quality and distribution are likely to be affected by climate change.

	Heritage	The Australian Government has responsibilities for the identification, management and protection of world heritage properties in Australia, and the protection of properties on the National Heritage List and Commonwealth Heritage places.	Climate change is likely to put additional stress on some heritage properties.
	Conservation	The **Natural Heritage Trust** was set up by the Australian Government in 1997 to help restore and conserve Australia's environment and natural resources. Since then, thousands of community groups have received funding for environmental and natural resource management projects. It includes the: • Landcare Program reversing land degradation and promoting sustainable agriculture (managed through the Department of Agriculture, Fisheries and Forestry); • Bushcare Program contributing to conserving and restoring habitat for our unique native flora; • Rivercare Program contributing to improved water quality and environmental condition in our river systems and wetlands; • Coastcare Program contributing to protecting our coastal catchments, ecosystems and the marine environment; and • Weeds of National Significance Program.	Climate change is likely to impact on the conservation of natural resources through changes to water availability, increased temperatures and changes to the spread of weeds, pests and diseases.
	Great Barrier Reef Murray Darling	**The Great Barrier Reef Marine Park Authority** has been established to provide for the protection, wise use, understanding and enjoyment of the Great Barrier Reef in perpetuity through the care and development of the Great Barrier Reef Marine Park. **The Murray–Darling Basin Initiative** is also relevant to this portfolio (see under DAFF). **Other policy interests** include: • Australia's Ocean Policy and coastal sustainability; • Environmental protection – air quality, ozone and chemicals; • Wetlands policy of the Australian Government; and • Antarctic and sub–Antarctic territories.	Sea level rise and sea temperature rise are likely to impact on the reef and local industries.
	Greenhouse and climate change	**The Australian Greenhouse Office** is responsible for developing policy advice and delivering programmes in response to global climate change. This includes strategies to reduce greenhouse gas emissions and programmes to adapt to climate change. The National Climate Change Adaptation Programme, the Greenhouse and Regional Australia Programme and Cities for Climate Protection are particularly relevant to this report.	
Department of Health and Ageing	Human health Biosecurity	The Australian Government is investing in programs to ensure effective preparation against potential new infectious diseases or terrorism. It is continuing to regulate and promote the safety of our food supply. These include: • protecting Australia against potential pandemic influenza and bird flu; • strengthening national health security, preparedness and response capability in the event of a terrorist attack or a national health emergency;	The increasing spread of vector–borne diseases with increasing temperatures will impact on health and health services. Heat waves, bushfires and increasing frequency of storm events are also likely to impact on mortality

		• establishing better disease surveillance systems to improve the national capacity to rapidly identify a disease outbreak or health emergency, whether introduced or naturally occurring; • enhancing Australia's public health diagnostic laboratory capacity to diagnose outbreaks of infectious diseases; • strengthening national health preparedness and incident response capability through improved planning, preparation and coordination of natural health responses to any major health incident arising from either natural events; • establishing the Health Emergency Incident Room to ensure that this facility is able to support the department in leading the health response to a national emergency; and • continuing to support Food Standards Australia New Zealand (FSANZ) to help ensure we have safe, high quality food by developing effective food standards for Australia and New Zealand.	and morbidity. Vulnerable population groups include the elderly and Aboriginal and Torres Strait Islanders.
Department of Foreign Affairs and Trade and AusAID	Climate change and the Pacific Island nations	The Australian Agency for International Development (AusAID) is an agency within the Department of Foreign Affairs and Trade. It manages the Australian Government's official overseas aid program aiming to advance Australia's national interest by helping developing countries reduce poverty and achieve sustainable development. AusAID works with neighbouring countries to improve the way their governments deliver economic and community services. One example is the South Pacific Sea Level and Climate Monitoring Project.	Sea–level rises and increasing cyclone/storm activity are likely to impact on the future development in many Pacific Island nations.
Department of Education, Science and Technology and CSIRO	Research support and infrastructure	The **National Research Priorities** include a priority for an "environmentally sustainable Australia". One of the themes is "Responding to climate change and variability". The aim is to increase understanding of the impact of climate change and variability at the regional level across Australia, and address the consequences of these factors on the environment and on communities. The **CSIRO Flagship research projects** includes a number of relevant areas: • Water for a Healthy Country which aims to achieve a tenfold increase in the social, economic and environmental benefits from water by 2025. • Wealth from Oceans which aims to position Australia by 2020 as an international benchmark in the delivery of economic, social and environmental wealth based on leadership in understanding ocean systems and processes. • Food Futures aims to transform the international competitiveness and add $3 billion annually to the Australian Agrifood sector by the application of frontier technologies to high–potential industries. • Energy transformed which aims to develop low–emission energy technologies and systems delivering cost–competitive energy services that meet the economic, social and environmental needs of Australians. The goal is cost effective reduction of greenhouse gas emissions from the energy sector.	Key research directions may need to change over time depending on the impacts of climate variability.

Source: The Allen Consulting Group

5.4 Prioritising vulnerable systems and regions

The foregoing discussion (in this chapter and those previous) has highlighted what we know, and what remains to be known, about the potential pressures on, and responses of, important systems under the influence of climate change. Much remains uncertain. But there is enough evidence and analysis to make reasonable judgements about areas of greatest risk, and begin to assign priorities for further research and planning activity. Extensive discussions with stakeholders have helped identify prospective areas for further research and policy development.

The framework highlighted at the beginning of this report is a basis for comparative risk assessment of different sectors and regions. It is useful to reflect on the analysis and discussion of this and previous chapters in the context of that framework.

Each of the elements of the framework — climate exposure, system sensitivity, adaptive capacity, adverse implications and potential to benefit — are summarised below. A comparative risk assessment (Table 5.4) provides an analysis of sectors and regions.

Climate exposure

Science is providing a progressively clearer and more accurate depiction of the dynamics of the global climate system, and how observed patterns of climate might change in response to increasing levels of greenhouse gas in the atmosphere. However, uncertainty about the trajectory of emissions in the future, coupled with micro–geographic factors and natural and chaotic influences, mean that it is not possible to give definitive forecasts of the climate conditions that will characterise a region in 30 or 50 years time. Forecasts of this type are necessarily uncertain and likely to remain so, even though levels of uncertainty can be expected to be reduced over time.

However, three salient points emerge from consideration of climate exposure:

- increases in average temperature and sea level are in prospect;
- key weather systems are likely to be affected with potentially significant implications for Australian rainfall; and
- rising temperatures can lead to increasingly 'energetic' climate systems, with the threat of more frequent and violent storm activity (i.e. 'extreme weather events').

For those wishing to adopt a conservative approach to the current greenhouse science it would be prudent to at least reflect on the lower bounds of climate change forecasts as they relate to variables such as temperature, precipitation, sea level rises etc. This should increasingly be considered as 'common ground'.

Prudent strategic preparations for climate change should view these climate change 'minima' as a starting point — planning and action can be continually updated as knowledge improves and uncertainty diminishes.

System sensitivity

All systems are in some way exposed to climate, and will therefore be affected by change in these conditions. A complete stocktake of systems and sensitivities is not available but particular attention must be paid to systems that are already under stress from other factors (such as growing population) or are operating near their natural climate limits. It remains for each and every decision maker to make an assessment of how reliant they are on climate conditions, and how changes in climate may, or may not affect them. Assessment of sensitivity should also extend to thinking about reliance on a system which is itself heavily impacted by climate influences. We have only begun to explore and understand the tapestry of detailed economic and physical relationships that link activities together, and how these are affected by changes in climate. However, we can readily identify a handful of key systems that are strongly influenced by climate and which may be sensitive to change. There are a number of systems that are arguably already approaching the limits of their capacity to cope with current climate conditions and related stresses.

Natural systems are obviously sensitive to climate influences, and some ecosystems are particularly fragile. The Great Barrier Reef is a high profile example, and alpine, mountain rainforest and wetland environments are others. The recent drought has tested many of these, and climate change could put considerable stress on important and valuable species.

A number of human systems are also clearly dependent on plant and animal biology. Agriculture, forestry and fishing are obvious examples. However, sensitivity varies. Horticulture may be affected by changes in frosts or by changes in extreme events such as hot spells and hail but sensitivity is not high. The Tasmanian Atlantic salmon aquaculture industry, on the other hand, currently operates at the high end of its temperature range and is therefore quite sensitive to increases in temperature.

Aspects and areas of tourism are also clearly linked to natural systems, as well as perceptions of local weather conditions by visitors and tourists. Operations based around natural assets such as Kakadu, the Great Barrier Reef, Australia's alpine regions or coastal resort destinations are likely to be sensitive to climate influences.

The economies of regions that are heavily dependant on these activities will also be climate sensitive. The Cairns and Murray Darling Basin regions clearly feature in this regard, with other parts of Australia sharing these characteristics to varying degrees. Mounting concern regarding water availability in key regions and population centres such as south western Australia (focused on Perth and Fremantle), Adelaide and the Sydney Basin also highlight sensitivities to possible climate changes.

The potential for extreme events, including storms and heatwaves, is also relevant. Many systems have a capacity to tolerate adverse climatic effects up to a certain threshold, and then exhibit extreme sensitivity to those conditions. The 'coping capacities' of all systems are important in this regard — and the likelihood and consequences of their failure.

Note that the combination of climate exposure *and* system sensitivity point to the potential impacts that would be experienced in the *absence* of an adaptive response. These elements come together to provide a warning of the possible implications of climate change for a particular system. Very sensitive systems stand to face significant consequences — even under low level climate changes.

Adaptive capacity

Adaptive capacity can be difficult to evaluate for some sectors. However, we can refer to evidence and experience from the past to guide judgement and priority assessment in this area. Key factors include:

- the trend rate and nature of climate variability and climate change in many areas is likely to far exceed the inherent (autonomous) adaptive capacity of many plants and animals, but be consistent with the modification and/or replacement timeframe available for most human systems;
- human systems (including managed biological systems such as agriculture) tend to deal well with change through an ability to anticipate challenges and opportunities and respond flexibly when these arise;
- the adaptive capacity of human systems is likely to be constrained when key assets are long lived and, once in place, cannot be readily modified or adjusted; and
- sufficiently rapid and extreme changes can overwhelm any system.

For the comparative risk assessment, *vulnerability* has been used which incorporates exposure, sensitivity and adaptive capacity.

Adverse implications

There are currently few studies that attempt to put a value on the costs to the nation or local community of important systems faltering or failing under the influence of climate change, or associated extreme events. Because industries and systems are interlinked an economy–wide (or indeed, integrated climate–population–economy) model would be the appropriate tool to undertake this analysis — but even then data and other information constraints would be a significant impediment to obtaining accurate and reliable comparative analysis. A raft of problems applies including valuation of environmental factors, changes in relative prices and economic relationships over time and valuing the human dimensions of climate impacts.

At this stage, we must make judgments about the inherent values of systems from both an economic and social perspective. Contributions to the economy are important, and changes in this can be judged against metrics such as income, employment and contributions to the nation’s capital stock. But contributions to regional economies can also be important, together with concerns about community health and wellbeing. Ideally, we should also examine the costs associated with changes in the incremental performance of systems under alternative levels and timeframes of climate change.

Potential to benefit

As indicated, there has been little comprehensive analysis of alternative adaptation strategies that could be applied to particular systems, their cost, or their likely effectiveness. Yet it is widely recognised that the effectiveness of human effort in assisting fragile species or ecosystems cope with climate change may be severely constrained. For instance, one might respond to the threat posed to the Great Barrier Reef or alpine ecosystems by alleviating other pressures, but low end climate change threatens to put significant (and possibly terminal) stress on these systems even with extraneous pressures removed.

Although 'potential to benefit' is an important consideration in developing adaptation research and response priorities, it is too early to rule any system out of consideration on the basis that it would be unresponsive to efforts to supplement its existing capacities for resilience and adaptation. Such a judgment would need to be formed on the basis of future experimentation, observation and effort. However, in considering criteria that are relevant to priorities for future government action, it can be important to extend thinking on the likely *responsiveness* of systems to government action to the *need* for government action.

5.5 Applying the priority framework

The current state of knowledge leaves no choice but to apply the priority framework using the information that is available to make the best possible judgements against each criterion. The alternatives — waiting until further research fills the gaps in our knowledge or treating all sectors and regions as being of equal priority — would mean postponing adaptation planning far into the future or dissipating resources.

The quality and quantity of information available to make judgements will vary between sectors, and comparative assessments will have to be made recognising that we have better information about, for example, irrigated agriculture than fisheries. It is possible to identify some proxy indicators that are helpful in thinking about the sort of information that is relevant to each criterion in the framework. We need not, however, limit consideration to these proxy indicators if other relevant information is available.

Potential impact (exposure plus sensitivity)

Proxy indicators:

- sensitivity to low range climate change and/or extreme events;
- known climate–related thresholds reached;
- systems operating at known climatic limits;
- loss of biodiversity; and
- systems subject to multiple–stresses.

Adaptive capacity

The following proxies are negative indicators of adaptive capacity:

- reliance on biological systems;
- reliance on long lived core assets;
- constraints imposed by current development patterns; and
- system flexibility to change is low.

The following proxies are positive indicators of adaptive capacity:

- ability to cope with current climate variability and similar 'shocks' (e.g. swings in international market prices;
- well established networks and mechanisms for generating and applying new knowledge; and
- resource mobility.

Adverse implications

Proxy indicators:

- implications of system failure; and
- economic, social, cultural or ecological importance.

Potential to benefit

Proxy indicators:

- absence of private ownership/ responsibility;
- strong non–market spillover costs/ benefits; and
- difficulties in coordinating private effort across dispersed groups.

Table 5.4 is a comparative risk assessment of the 'candidate' sectors and regions discussed in chapters 3 and 4 of this report. The judgements presented are based on material in these chapters.

Table 5.4

COMPARATIVE ASSESSMENT OF 'CANDIDATE' SECTORS AND REGIONS

Sector or region	Vulnerability	Adverse implications	Potential to benefit	Comparative assessment
Fishing	High for a limited number of species, uncertain for others.	Annual fisheries production valued at $2.5 billion, exports $1.6 billion.	Uncertain.	Merits some attention. Some threat to an industry of considerable value.
Tourism	High in some locations where tourism depends on natural attractions threatened by climate change. Impact on international tourist numbers uncertain but could be significant.	Tourism valued at $32 billion, employs 5.7 per cent of workforce.	Potential for diversification, changes in marketing strategies and preventative investments such as beach repair and snow–making in ski resorts is high.	Requires attention. High value industry that may be adversely affected in some important regions.
Water supply	High in most areas, especially where water resources are already under stress. Likely reductions in run–off will affect water supply to settlements and irrigated agriculture.	Irrigated agriculture valued at $9.6 billion a year. Water security is critical for settlements. The ecological values of aquatic ecosystems depend on adequate environmental flows.	Potential to benefit is high and planning horizons long, underlining the need for early attention to adaptation planning. Climate change needs to be factored into processes already under way to improve management of water resources.	Requires urgent attention. Resource has critical economic, social and ecological values, climate change likely to exacerbate existing stresses. Long–term planning essential.
Energy	Potentially high in some areas and circumstances. Increased peak demand. Transmission and distribution infrastructure very vulnerable in some areas, particularly to extreme weather events.	Power supply is an essential service for the economy, health, safety and households.	Adaptation planning is feasible and can fit with existing planning regimes.	Requires urgent attention. Potential risks to this essential service must be considered in long–term planning.
Buildings and settlement s	High. Main vulnerabilities related to sea level rises and extreme events such as floods, storms, storm surges, cyclones, heat waves and bushfires. Northern and coastal settlements are most vulnerable. Vulnerability of remote Indigenous settlements may be exacerbated.	Average annual cost of weather–related natural disasters is $900 million – likely to increase with climate change. Increased risk to human life is also likely.	A number of planned adaptive responses are feasible, including changes to building standards, emergency management planning and urban planning.	Requires urgent attention. Risks are high but planning and response systems are complex.

Health	Moderate. Potential expansion of vector–borne diseases, although existing disease control measures are likely to contain these. Possible increased incidence of food–borne diseases and risks from extreme events (see under buildings and settlements). Remote Indigenous communities are more vulnerable than populations in major cities.	If potential loss of life from extreme events (considered as part of settlements above) is excluded, costs associated with the health impacts of climate change over the next few decades are likely to be relatively minor. Some groups or remote settlements may incur greater relative costs.	Adaptive responses are feasible and likely to constitute an extension of existing strategies, such as quarantine and biosecurity measures.	Merits some attention. 'Mainstreaming' climate change adaptation into existing strategies will be the key.
Agriculture	High in most industries. Increased drought likely to adversely affect cropping and animal industries. Reduced runoff in Southern Australia likely to adversely affect irrigated agriculture and dryland cropping. Reduced frost days may have some negative effects on horticulture. Change in pest and weed distribution and in global markets also likely. Offsetting benefits in some industries are possible, e.g. reduced waterlogging in some cropping areas or potential carbon dioxide fertilisation effects. Agricultural industries have demonstrated considerable resilience to past climate variability.	Agriculture gross value–added is about $20 billion, or 3% of GDP. It is an important export industry and farmers manage about 60% of Australia's land by area. Significant decline in agriculture would have serious adverse implications for employment, trade and land management.	A number of practical adaptation options for agriculture have already been identified, and further research is likely to reveal others.	Requires urgent attention. Supports an important element of Australia' economic and social fabric and is highly vulnerable to the effects of climate change.
Forestry	Moderate. Increased fire danger, changes in the distribution of pests, a likely drying trend, and increased soil erosion due to extreme rain events are likely to adversely affect forest production. Carbon dioxide fertilisation and lengthened growing seasons may be offsetting factors.	Forestry contributes about one per cent to GDP and directly employs over 18,600 people.	Forestry has the potential to benefit from early attention to adaptation planning through better selection of species and management planning that takes climate change into account. Planning horizons in this industry are relatively long.	Requires attention. The industry is important and vulnerability is moderate. There are some potential benefits that could be exploited with careful planning.

Biodiversity	High. Increased temperatures, reduced rainfall over much of Australia, the spread of pests and weeds, changed fire regimes and sea–level rise will adversely affect many terrestrial, aquatic and coastal ecosystems. Higher temperatures, possible changes in ocean currents, and potential changes in ocean chemistry will affect marine ecosystems. Some ecosystems are particularly vulnerable, notably coral reef systems (including the Great Barrier Reef), coastal wetlands (including Kakadu), alpine areas, fragmented terrestrial ecosystems and the heathlands of south–west Western Australia. Environmental flows of key riverine systems are also vulnerable, with increased competition for diminishing water resources. Autonomous adaptive capacity is low, especially where systems are already under stress.	Australia is one of the twelve most biologically diverse nations in the world, and the only one that is developed. Eighty per cent of flora and fauna are unique to Australia. Most of Australia's sixteen World Heritage areas were listed for their natural values.	Potential to benefit from planned adaptation varies. There is considerable scope to increase the resilience of many systems by relieving other stresses. A National Climate Change and Biodiversity Action Plan has been agreed by all jurisdictions.	Requires urgent attention. Vulnerability is high, natural systems have limited autonomous adaptive capacity, and biodiversity has enormous cultural, social and economic significance.

Note: Vulnerability combines exposure, sensitivity and adaptive capacity

Priority outcomes

Current sectoral priorities for adaptation research and supplementary action to emerge from the analysis are (in priority order):

Biodiversity and ecosystems

Research in this area should focus on stressed, highly sensitive and rare species and ecosystems (the responsiveness of biological systems to efforts to supplement their natural coping and adaptive capacities should be monitored and reviewed). Key focuses should include:

- alpine regions — which are sensitive to any significant increase in temperature and reduction in snow cover;
- reef systems — including the Great Barrier Reef and Ningaloo — which are sensitive to temperature change, sea level rises and changes in the surface chemistry of the ocean arising from increased atmospheric CO_2. Many parts of the Great Barrier Reef are under pressure from poor water quality and crown of thorns invasions, which might in turn be linked with loss of predator fish species. These other pressures reduce the capacity to recover from temperature related bleaching events;
- isolated tropical montane rainforests — these are 'trapped' systems with nowhere to go. Many species could be lost in the Wet Tropics;
- heathland systems in southwest Western Australia — these are incredibly biodiverse and already under pressure from habitat fragmentation and salinity. They are trapped from further southward migration of other species as temperatures warm;
- coastal mangrove and wetland systems (including Kakadu) — these areas will be vulnerable to sea–level rise with those that are freshwater/brackish transition zones particularly exposed; and
- rangelands — in the south and east from drying and in the North from woody weed invasion (vegetation thickening).

Importantly the 'value' and uniqueness of World Heritage listed areas and ecosystems (such as the Great Barrier Reef and Kakadu) is already established and these should be given prominence on adaptation research and planning. Quite apart from their ecological importance, heritage areas also have a strong and established role in supporting eco–tourism activities and regional economies. It must also be recognised that there may be more that could be done to assist some vulnerable species and ecosystems than others.

Agriculture

Agriculture is a heavily climate dependent sector with strong significance for the Australian economy and regional communities. It has diverse needs and a traditionally strong requirement for government support in coordinating R&D efforts and other strategic and adjustment activities due to the number, dispersion and frequently small size of individual stakeholders.

The focus here should be on:

- those already stressed — economically or biophysically, as a result of land degradation, salination and loss of biodiversity;

- those at the edge of their climate tolerance; and
- those activities where large and long lived investments are being made — such as in dedicated irrigation systems, slow growing cultivars and processing facilities.

Water supply

Every major mainland city faces water stress already, and it is a critical and increasingly important natural resource. In many cases climate change will increase these pressures through increased temperature and possibly lower rainfall with more frequent ENSO events. It is imperative that climate change risks factor into water planning activities. Although the risk of prolonged droughts is a major factor — particularly in the south — the threat from higher rainfall (in the north) and extreme events is also relevant. Dams could be susceptible to extreme rainfall if these exceed historical design standards. Dam overtopping and failure can have catastrophic short and medium term effects in terms of human and economic losses.

Settlements, structures and emergency services

Exposure of our cities to climate patterns is high — but the sensitivity to change depends very much on the way it impacts on extreme events. Urban areas and the built environment are machines to manage and control climate. Our cities and infrastructure are built to accepted risk limits based on the expected return frequency of severe winds, heavy precipitation events, storm surges and so on. Below these thresholds, severe weather events are usually handled with relatively light damage to property and human health and life. Above the thresholds, however, damage, injury and death can accelerate in a non–linear way. This highlights the need for building and zoning standards for long lived structures (e.g. houses, buildings, exposed structures) to take future climate change into account, and the risk that structures and settlements subject to old construction and zoning standards might be increasingly susceptible to costs in the future.

If climate change increases the energy of tropical cyclones and severe non–tropical depressions then the return frequency of severe storms could reduce significantly. Linked with increasing sea level and hence more dangerous and extensive storm surges, this could put some of our significant population and tourist centres like Cairns, Broome, Darwin and Townsville, as well as remote communities susceptible to isolation through flooding, at considerably increased risk.

In many temperate urban and rural centres, any increase in severe weather events linked with climate change — bushfires, heavy and sustained rainfall, high winds and in particular cyclones, sustained heatwaves — could cause significant damage. This is particularly so in inner areas of older cities where population density is high and old stormwater infrastructure struggles to cope with existing run–off loads. Demographic changes could exacerbate these effects as they impact both on the volunteer base for emergency services and increase the population at risk.

Energy supply and major infrastructure

Demand for energy is temperature sensitive (increasingly so with the penetration of domestic air–conditioning) with peaks both changing from winter to summer and steepening. Supply is sensitive both to extreme weather related events and in some cases temperature itself as it degrades transmission capacity. Supply sensitivity includes disruption to platform operations (as has happened recently in the Gulf of Mexico with direct consequences for global energy prices), transmission and distribution (including impacts of land slip and storm on very long gas pipelines and storm and bushfire on electricity transmission and distribution).

Most of Australia's energy infrastructure — generation and transmission and distribution — is now at, or approaching, the point where there is little redundancy at peak periods and reduced capacity to sustain cumulative impacts. Our economic, social and household systems are now so interdependent while being simultaneously dependent on a reliable, high quality energy supply that a failure in that supply brings much higher economic and social costs than at any time in the past. There may be a need for a capacity safety margin to take account of the additional pressures that might be placed on infrastructure by climate change. This could be achieved through pricing review as much of the sector is subject to price regulation in one form or another. It could also be achieved through demand side management programs and policies.

Other industries

Elements of the fishing, forestry, tourism and health care industries are also threatened by climate change, but the pattern is mixed. Pressures in these sectors can be highly species specific or regionalised, and are most effectively addressed on that basis. Typically, these sectors exhibit higher degrees of resource mobility, flexibility and/ or resilience to low level climate change than those highlighted above. But this does not preclude the possibility for high priority – high vulnerability activities within these broad groups to come to light as a result of ongoing discussion and analysis.

Regional priorities

This approach adopted here can be readily applied to a more disaggregated analysis of potentially vulnerable industries and activities. Although regional climate change analysis is being continually refined, data sets currently exist that can be used to determine the economic make up and dependence of regions at a relatively fine scale. The ABS. for instance, provides sectoral information for around 200 Statistical Sub–Divisions (SSDs) in Australia, and the MMRF economic model operated by the Centre of Policy Studies at Monash University identifies 37 industries in 57 regions.

Priority regions can be identified using this framework and current findings. These are those with a strong reliance on highly vulnerable industries or assets, or which represent populations already experiencing stresses that climate change pressures could easily exacerbate. They are sensitive to low level climate changes (as indicated by current regional climate modelling) and face significant costs from additional climate pressures — often with limited adaptive capacity because of restrictions in resources and incomes:

- **low lying coastal population and resort centres**
  - those are vulnerable to inundation and erosion from storm surges

- **tropical and sub–tropical population centres**
  - vulnerable to extreme weather events
- **alpine regions**
  - vulnerable to rising temperatures
- **centres with a high dependence on agricultural and/ or eco–tourism activities**
  - vulnerable to economic pressures
- **remote Indigenous communities**
  - vulnerable to health and isolation pressures, low income levels suggest constrained adaptive capacity
- **areas of southern Australia facing acute water shortages and supply constraints**
  - these shortages are likely to be exacerbated under climate change

These characteristics point immediately to the following regions as high priorities for further adaptation planning and effort;

- Cairns and the Great Barrier Reef;
- Murray Darling Basin; and
- South-West Western Australia.

However, further research and consideration by stakeholders may well see this list extended and refined. Climate pressures can also be significant for localised communities in coastal storm prone and low–lying areas, far north Australia (particularly Indigenous and rangeland communities) and in alpine regions.

In addition to these sectors and regions, a number of important cross cutting processes and actions can be identified for consideration under the National Climate Change Adaptation Programme.

Facilitating effective planning, preparations and responses to the threats posed by climate change is a large and challenging task. It will be important to achieve a high degree of 'leverage' from the existing resource commitment and ensure significant stakeholder engagement in the agenda for action.

Appendix A

Terms of reference

The Australian Greenhouse Office outlined the following tasks and objectives for this report.

The key output will be a report that provides a high–level strategic risk and vulnerability assessment of climate change impacts for governments, the economy and industry sectors, and regional communities in Australia.

Issues for coverage in the report include:

1. A statement of purpose and scope and an outline of the methodology employed

2. A brief contextual overview of Australia's vulnerability to climate change

3. High–level discussion of risks of climate change impacts, spanning

- Key industry sectors, including
  - impacts on the production base
  - impacts on markets and terms of trade
  - risks from lower probability but high impact
- Select highly vulnerable regions and regional communities
- Achievement of Government objectives
  - effectiveness of identified policies should consideration of climate change impacts and appropriate adaptation strategies not be incorporated
  - implications for maintaining effectiveness of key program investments

4. Comparative risk assessment of climate change impacts for Australia

5. Conclusions on risk management priorities and approaches for the Australian Government, and for planning and decision making in industry and by regional communities

6. A reference list and an outline of consultations undertaken.

Appendix B

Standard setting for major services and infrastructure

The risks of severe weather events on infrastructure within Australia will ultimately fall on the infrastructure safety regulators. The regulators set the standards that govern specific types of infrastructure within their jurisdiction, which are as a rule managed at the State/Territory level and coordinated through national councils at which State/Territory authorities attempt to harmonise their respective codes. Below is a short introduction to the bodies that would be charged with examining the impacts of climate change on key infrastructure within Australia.

Electricity

For the electricity industry, infrastructure requirements are managed by the respective State and Territory electricity safety regulators. For example, within Victoria, safety standards for the electricity industry are set by the Office of the Chief Electrical Inspector (OCEI). As an independent and technical regulator, the OCEI shapes the safety standards for the electrical industry in Victoria and, through the Electricity Regulatory Authority Council (ERAC) attempts to influence national adoption of safety regulations.

ERAC is the council responsible for the liaison between the technical and safety electrical regulatory authorities of eight Australian States/Territories and New Zealand. Each jurisdiction sends the head of its authority to an ERAC meeting in order to meet and discuss best practice for the electricity industry with key industry bodies (not restricted to safety regulators only). The decisions made at the ERAC are then brought back to each jurisdiction and adopted as technical electrical regulation. While there is no specific process for dealing with climate change, if a whole of government approach were adopted to make climate change a priority, this would be the mechanism by which national standards would be set.

Dams

Dam safety standards are also set by respective state regulatory bodies. However, the standards are often developed by The Australian National Committee on Large Dams (ANCOLD). ANCOLD is an incorporated voluntary association of organisations and individual professionals with an interest in dams in Australia. Members include local, state and federal agencies, dam owners and operators, contractors, consultants and academics. Many disciplines are represented including planners, environmental scientists, engineers, hydrologists, geologists, social scientists, economists and legal practitioners. ANCOLD's objective is to encourage improvement in the planning, design, construction and operation of large dams in Australia. This is accomplished in part through the development and publication of dam design standards. The common practice is for State regulators to require that infrastructure meet the guidelines developed by ANCOLD.

Currently, ANCOLD does not have a methodology for addressing climate change issues specifically, however climate change would be addressed through a dam safety review, which occurs approximately every 20 years, depending on the jurisdiction. These dam safety reviews incorporate the latest knowledge around future weather events, which is based on BOM estimations.

Water Infrastructure

Water infrastructure — including sewerage, pipelines and drainage infrastructure for urban subdivisions — is managed at the council level by local government. The council determines the design criteria, supervising all water infrastructure within its boundaries. Decisions are made on the tolerance levels through a consideration of safety, cost and risk management issues. For example in the NSW Tweed Shire Council, the Council has adopted criteria set out in the Queensland Urban Drainage Manual, which helps to streamline decisions and is more appropriate for the Tweed Shire due to climatic conditions. The council engineers then determine, using Australian Rainfall and Runoff published by the Institute of Engineers Australia, what level of tolerance to build into the water infrastructure — from Q2 (1 in 2 year storm level) to Q100 (1 in 100 year storm level) — depending on cost and safety tradeoffs. Generally subdivision drainage systems are estimated to have a Q5 level of safety, with the expectation that the roads will be able to carry any excess.

Climate change considerations would generally be expected to be incorporated into Australia wide council decisions if the Australian Rainfall and Runoff handbook were to change, as this is considered to be the best available information on design flood estimation (assuming there were adequate funding available). Cost constraints at the local level could potentially result in the under–designing of new water infrastructure.

Buildings

All buildings constructed in Australia must adhere to the Building Code of Australia. The Building Code is overseen by the Australian Building Codes Board (ABCB) — a joint initiative of all levels of Australian Government, which works in co–operation with the building industry. The ABCB is responsible for:

- developing and managing a nationally uniform approach to technical building requirements, embodied in the Building Code of Australia (BCA);
- developing a simpler and more efficient building regulatory system; and
- enabling the building industry to adopt new and innovative construction technology and practices.

The ABCB periodically reviews the Building Code as technology, knowledge and community needs change. The ABCB upon reviewing the Building Code may decide to develop a new industry standard, which it typically contracts out to Standards Australia, who will develop the structural engineering technical specifications that ensure the code will be met by builders going forward.

Zoning

In terms of zoning and town planning regulations — which determine whether an area is suitable for residential development — the method by which zones are set is fundamentally the same: rezoning issues are in general identified by local councils, who prepare submissions, which are then vetted by a State authority and subject to Ministerial approval. However because states and territories have different legislative histories, different requirements for agency input and different coordinating bodies, which sit within different government departments, the ultimate process and outcomes can appear to have quite different 'bents'. That is, in the balancing act that is town planning, some criteria might be given more priority in one jurisdiction than they would in another. To elaborate on the process by which zoning laws are set we consider three jurisdictions: NSW, Western Australia, and South Australia.

In NSW, although the Department of Infrastructure, Planning and Natural Resources provides the final approval for a re–zoning initiative, local councils perform the main part of the work to get an area re–zoned. They assume all of the administrative tasks, investigate the merits of the re–zoning rule, make recommendations and provide preliminary approval. In this way, if climate change were to require the re–zoning of certain areas, the Department of Infrastructure, Planning and Natural Resources would serve as a coordinator among the local councils in a governing role but the majority of the work would be initiated by local councils.

In Western Australia, local councils as a rule generally drive town planning and zoning. Like NSW, proposals for re–zoning are vetted by the State planning authority. The process is such that councils advertise the proposal, call for submissions from the public and produce a report, which receives final approval from the WA Planning Commission and WA Minister for Planning. Thus the process is typically driven by local councils with oversight from State bodies. However, in the case of climate change, the process might be driven by the State government. For example, if an area that was previously suitable for residential development — such as, say, a section of land between a highway and a beach — became unsuitable for development due to increasing frequency of severe weather events, which might possibly render the area a swamp, the WA Planning Commission could feasibly override local councils. The Commission could do so by declaring the area a reserve under the Metropolitan Region Scheme, which would force local councils to comply with the new zoning regulation.

Within South Australia, Planning SA is the State authority that coordinates agency consultations about a zoning proposal. Local councils generally initiate a project, and then Planning SA runs a process for the relevant single issue agencies to submit commentary. Planning SA also ensures that all zoning proposals adhere with the State's Strategic Plan and Planning Strategy, which is periodically reviewed and could possibly include specific requirements. These requirements could feasibly mandate that all developments consider climate change impacts.

Most planning authorities have emphasised that planning is about balancing issues, not prioritising one concern over another — and further, that unless there were strong signals at a political level that an issue, such as climate change, was a whole of government priority, that it is unlikely that significant changes will be adopted at a local level.

Transport — Major roads and bridges

Major road standards are regulated at both a State and Federal level, depending on the type of road to be constructed. For example, the following authorities oversee the regulation of road transport — including the planning, designing, building and maintenance of the roads and associated infrastructure (such as bridges) — within their jurisdiction:

- Roads and Traffic Authority New South Wales (RTA NSW)
- Roads Corporation Victoria (VicRoads)
- Department of Main Roads Queensland (DMR Qld)
- Main Roads Western Australia (MR WA)
- Department of Transport and Urban Planning South Australia (DTUP SA)
- Department of Infrastructure, Energy and Resources Tasmania (DIER Tas)
- Department of Infrastructure, Planning and the Environment Northern Territory (DIPE NT)
- Department of Urban Services Australian Capital Territory (DUS ACT)
- Australian Government Department of Transport and Regional Services (DOTARS)

These bodies co–ordinate their actions through Austroads, an association of Australian and New Zealand road transport and traffic authorities, which also provides expert advice to Australian Transport Council (ATC) and the Standing Committee on Transport (SCOT).

Climate change is already being considered by Austroads. In a recent report it examines the impact of climate change on road demand, pavement performance, and road design and maintenance.[160]

Minor road and bridge standards and design are managed at a Council level. Local councils balance cost, safety and risk management concerns to design transport infrastructure within their jurisdiction.

Transport — Rail

Rail is regulated at a State level. Each rail owner/track operator must become accredited by the states through which their rail network flows. For example, any operator wishing to manage a track within South Australia is required to get accreditation from Transport Australia. Once accredited the track owners are responsible for the management of their infrastructure.

[160] Austroads 2004, op. cit.

Ports

Ports are regulated by the respective Port Authority of each state. Standards for dredging, safety and navigation aids are set by State authorities, though these standards are generally aligned with international standards, which are determined in the main by the International Maritime Organisation and divisions of the International Standards Organisation. For example within Victoria, this function sits within the Department of Infrastructure, which aligns its navigational aid requirements with those of the International Association of Lighthouse Authorities, a division of the International Standards Organisation.

Appendix C

Reference List

Anaheim A. and Schjolden A. 2004, *An Approach to Utilise Climate Change Impacts Studies in National Assessments.* Global Environ. Change. 14, pp 147–160.

Akerlof G.A. and Dickens W.T. 1982, *The Economic Consequences of Cognitive Dissonance*, American Economic Review, June, pp 307–19.

Australian Building Codes Board 2003, *Guide to the BCA: Class 2 to 9 buildings.* Australian Building Codes Board: Australia.

Australian Bureau of Agricultural and Resource Economics (ABARE) 2000, *Impact of Farmer's Expenditure on Employment and Population in Australian Towns*, Current Issues, 2000.4, Canberra.

ABARE 2003a, *2002–03 Drought review of its impact on Australian agriculture,* Australian Commodities, vol. 10, no. 3, Australian Bureau of Agricultural and Resource Economics: Canberra.

ABARE 2003b, *Australia Commodity Statistics 2003,* Australian Bureau of Agricultural and Resource Economics: Canberra.

ABARE 2003c, *Australia Commodity Statistics 2003*, Canberra; World Bank 2003, *Global Economic Prospects and the Developing Countries 2003*, Washington.

ABARE 2004a, *Farm Survey Results, March,* Australian Bureau of Agricultural and Resource Economics: Canberra

ABARE and Fisheries Research and Development Corporation 2004b, *Australian Fisheries Statistics 2003,* Canberra.

ABC Western Australia (n.d.), http://www.abc.net.au/wa/stories/s1164601.htm, accessed 15 September 2004.

Australian Bureau of Statistics (ABS) 1995, *Drought in Australia* Australian Bureau of Statistics: http://www.abs.gov.au/Ausstats/abs@.nsf/0/6C98BB75496A5AD1CA2569DE00267E48?Open, accessed 26 August 2004.

ABS 1998, *Drought in Australia*, available at http://www.abs.gov.au/Ausstats/abs@.nsf/0/068F13BCCD03F27BCA2569DE001F1072?Open, accessed 26 August 2004.

ABS 2001, *1999–2000 Agriculture.* cat. no. 7113.0. Ausinfo:Canberra.

ABS 2002, *Australian National Accounts: National Income, Expenditure and Product.* available at http://www.abs.gov.au/Ausstats/abs@.nsf/94713ad445ff1425ca25682000192af2/d7418b964ce4e789ca256c240082a01c!OpenDocument.

ABS 2004a, *Population Projections Australia, 2002–2101.* cat. no. 3222.0. AusInfo: Canberra.

ABS 2004b, *Water Account Australia, 2000–01.* cat. no. 4610.0. AusInfo: Canberra.

ABS 2004c, *Year Book Australia, No 86, Canberra.* Catalogue No. 1301.0.

ABS Cat. 5204.0, Australian National Accounts, Table 70, Capital stock by institutional sector

ACCC 2002, *Insurance Industry Market Pricing Review*, available at http://www.accc.gov.au/content/index.phtml/itemId/321637

Australian Climate Group 2004, *Climate Change: Solutions for Australia.* prepared for Insurance Australia Group and World Wildlife Fund: Sydney.

Australian environmental cooperative research centres: *https://www.crc.gov.au/Information/about_CRCs.aspx*

Australian Greenhouse Office (AGO) 2002, *Living with Climate Change: An Overview of Potential Climate Change Impacts on Australia* Australian Greenhouse Office: Canberra.

Australian Institute of Health and Welfare (AIHW) 2004, *Australia's Health 2004*. AGPS Canberra.

Australian State of the Environment Committee 2001, *Australia State of the Environment 2001,* Australian State of the Environment Committee: Canberra.

Australian Tourism Net http://www.atn.com.au/wa/south/south–a.htm.

Austroads 2004, *Impact of Climate Change on Road Performance.* Austroads Publication No. AP–R243/04. Austroads: Sydney.

Bennett E. 2004, *Assistance is no dry argument*, Australian Financial Review, 29 July 2004, Special Report, p 7.

Bohdanowicz P. and Martinec I.M. 2001, *Thermal Comfort and Energy Savings in the Hotel Industry.* Proc. 15th Conference on Biometeorology and Aerobiology, Kansas City, Missouri, 28 Oct.–1 Nov 2002: American Meteorological Society, Boston, MA, pp 396–400.

Braganza 2004, *Simple indices of global climate variability and change II: Attribution of climate changes during the twentieth century.* Climate Dynamics, 22, pp 823–838.

Brown C.V and Jackson P.M. 1982, *Public Sector Economic*s, second edition, Martin Robertson & Company: Oxford.

Buddemeier R.W., Kleypas J.A. and Aronson R.B. 2004, *Coral Reefs and Global Climate Change: Potential Contributions of Climate Change to Stresses on Coral Reef Ecosystems* prepared for the Pew Center on Global Climate Change: Arlington.

Bureau of Industry Economics (BIE) 1994, *Energy Labelling and Standards.* AGPS: Canberra.

Bureau of Tourism Research (n.d.), *Australian Tourism Data Card:* http://www.btr.gov.au/service/datacard/datacard_action.cfm, accessed 5 August 2004.

Bureau of Transport and Regional Economics (BTRE) 2004, *Risk in Cost Benefit Analysis: Implications for Practitioners,* Working Paper 61, Bureau of Transport and Regional Economics: Canberra.

BTRE 2001, *Economic Costs of Natural Disasters in Australia*, http://www.btre.gov.au/docs/reports/r103/r103.aspx

Bureau of Transport Economics 2001, *Economic Costs of Natural Disasters in Australia,* Bureau of Transport Economics: Canberra.

Burton I., Kates R. W and White G. F. 1993, *The Environment As Hazard.* Second Edition, Guilford Press: New York.

Campbell B., Stafford Smith D. and McKeon G. 1997, *Elevated CO_2 and Water Supply Interactions in Grasslands: A Pastures and Rangeland Management Perspective,* Global Change Biology. vol. 3(3), pp 177–187.

Cairns & Great Barrier Reef Region website: http://www.tropicalaustralia.com.au/

Cairns Connect website: http://www.cairnsconnect.com/cairns/industry.asp

Castles I. and Henderson D. 2003, *The IPCC Emissions Scenarios: An economic–Statistical Critique,* Energy and Environment, vol 14, 2 and 3.

Castles I. 2004, *The Science of Hot Air,* The Australian, Sydney (4 June 2002).

Centre for International Economics 2004, *Implications for Water Reforms for the National Economy*, prepared for the National Program for Sustainable Irrigation, Canberra.

Changnon S., Pielke Jr R., Changnon D., Styles R. and Pulwarty R. 2000. *Human factors explain increased losses from extreme weather and climate events,* Bulletin of the American Meteorological Society, vol. 81. pp 437–442.

Church J.A., Hunter J., McInnes K. and White N.J. 2004, *Sea–level rise and the frequency of extreme events around the Australian coastline.*

Coleman T. 2002, *Insurance and Climate Change: An Australian Perspective,* Insurance Australia Group, Sydney.

Coleman T. 2002, *The Impact of Climate Change on Insurance Against Catastrophes,* Insurance Australia Group Working Paper.

Coleman T. 2003, *The Impact of Climate Change on Insurance against Catastrophes*, presentation to the Institute of Actuaries Australia 2003 Biennial Convention.

Commonwealth of Australia 2001, *Australian Agriculture Assessment 2001, National Land and Water Resources Audit*, Volume 2, Canberra.

Commonwealth of Australia 2002, *Intergenerational Report 2002–03,* Budget Paper No. 5, May 2002: Canberra.

Commonwealth of Australia 2004, *Natural Disasters in Australia: Reforming mitigation, relief and recovery arrangements.* A report to the Council of Australian Governments by its High Level Officials Group. Department of Transport and Regional Services, Canberra.
http://www.dotars.gov.au/ndr/index.htm

Copeland E.T. and Weston J.F. 1983, *Financial Theory and Corporate Policy*, 2nd Edition, Addison–Wesley Publishing: Massachusetts, NSW Treasury 1997 Guidelines for Financial Appraisal, Paper TPP pp 97–4,

Council of Australian Governments (COAG) 2004, *Intergovernmental Agreement on a National Water Initiative Between the Commonwealth of Australia, and the Governments of New South Wales, Victoria, Queensland, South Australia, the Australian Capital Territory, and the Northern Territory,* Council of Australian Governments, Canberra.

CSIRO 2001a, *Climate Change Impacts for Australia,* CSIRO Sustainable Ecosystems, Aitkenvale, CSIRO: Canberra.

CSIRO 2001b, *Climate Change Projections for Australia.* Climate Impact Group, CSIRO Atmospheric Research: Melbourne.

CSIRO 2002, *Climate Change and Australia's Coastal Communities, brochure:* available at http://www.dar.csiro.au/publications/CoastalBroch2002.pdf accessed 5 August 2004.

CSIRO 2004, *Sustainable Rangeland Systems:* available at http://www.cse.csiro.au/research/Program3/Sustainable_Rangelands.htm, accessed 6 August 2004.

Cuny F.C. 1983, Disasters and Development, Oxford University Press, New York.

Department of Environment and Heritage, www.deh.gov.au.

Department of Health of Ageing 2003, *Human Health and Climate Change in Oceania: A Risk Assessment 2002,* Department of Health of Ageing: Canberra.

Department of Health and Ageing 2004, *Australian Health and Ageing System: The Concise Factbook,* Canberra, Department of Health and Ageing: Canberra.

Department of Industry, Tourism and Resources (n.d.), http://www.industry.gov.au, accessed 5 August 2004.

Department of the Prime Minister and Cabinet 2002, *Commonwealth–State Ministerial Councils – A Compendium*, Department of the Prime Minister and Cabinet: Canberra.

Department of Sustainability and Environment 2004, *Adapting to Climate Change: Enhancing Victoria's Capability, prepared for the Victorian Government Department of Sustainability and Environment*, Department of Sustainability and Environment, Vega Press: Melbourne.

Department of the Treasury (n.d.), *The Impact of the 2002–03 Drought on the Economy and Agricultural Employment,* Department of the Treasury: http://www.treasury.gov.au/documents/817/HTML/docshell.asp?URL=03_article_2.asp, accessed 26 July 2004.

Department of Treasury and Finance WA 2001, *Economic Tools to Tackle Dryland Salinity in Western Australia, Economic Research Paper,* Perth, Department of Treasury and Finance WA.

Dixit, A. and Pindyck, R.S. 1994, *Investment Under Uncertainty,* Princeton University Press: Princeton N.J.

Dixit A. and Skeath S. 1999, *Games of Strategy,* W. W. Norton & Co: New York.

Driml S. and Common M. 1995, *Economic and financial benefits of tourism in major protected areas*, Australian Journal of Environmental Management, vol. 2, no. 1.

Easterling W.E., Hurd B.H., and Smith J.B. 2004, *Coping with Global Climate Change: The Role of Adaptation in the United States,* Pew Center on Global Climate Change: Arlington.

Environment Australia 2003, *Wetlands Australia — National Wetlands Update 2003,* Environment Australia: http:www.ea.gov.au/water/wetlands/publications. accessed 17 September 2004.

Etheridge D.M., Steele L.P., Langenfelds R.L., Francey R.J., Barnola J.–M. and Morgan V.I. 1996, *Natural and anthropogenic changes in atmospheric* CO_2 *over the last 1000 years from air in Antarctic ice and firn*, J. Geophys. Res. 101, pp 4115–4128.

Feenstra J.F., Burton I., Smith J.B., and Tol R.S.J. 2003, *Handbook on Methods for Climate Change Impact Assessment and Adaptation Strategies,* Institute for Environmental Studies: Amsterdam.

Frich P., Alexander L.V., Della–Marta P., Gleason B., Haylock M., Klein Tank A.M.G. and Peterson T. 2002, *Observed coherent changes in climatic extremes during the second half of the twentieth century*, Climate Res. 19, pp 193–212.

Gallop, Geoff The Hon. 2004, *Desalination plant to become a vital source for State's water supply, media release,* 29 July 2004 and Water Corporation www.watercorporation.com.au

Gans J.S. and King S.P. 2004, *Taking into Account Extraordinary Circumstances in Regulatory Pricing,* August, Business School: Melbourne.

Glanznig A. 1995, *Native Vegetation Clearance, Habitat Loss and Biodiversity Decline,* Biodiversity Series Paper No. 6, Biodiversity Unit, Department of Environment, Sport and Territories: Canberra.

Goklany I.M. 1995, *Strategies to enhance adaptability: Technological change, sustainable growth and free trade*, Climatic Change, vol 30.

Gollier C. 2001, *The Economics of Risk and Time*, MIT Press: Massachusetts.

Government of Canada 2004, *Climate Change Impacts and Adaptation: A Canadian Perspective*, Ottowa.

Government of South Australia 2004, *Water Proofing Australia; Exploring the Issues — A discussion paper,* Government of South Australia: Adelaide.

Grübler A., Nakicenovic N., Alcamo J., Davis G., Fenhann J., Hare B., Mori S., Pepper B., Pitcher H., Riahi K., Rogner H., La Rovere E., Sankovski A., Schlesinger M., Shukla P.R., Swart R., Victor N. and Jung 2004, *Emissions scenarios: a final response*, Energy and Environment, 15, pp 11–24.

Hansen J. 2004, *Defusing the Global Warming Time Bomb,* Scientific American, March, pp 68–77.

Henderson–Sellers A. and Blong R. 1989, *The Greenhouse Effect Living in Warmer Australia,* NSW University Press: Sydney.

Hennessy K.J. 2004, *Climate change and Australian storms,* In Proc. International Conference on Storms, Brisbane, 5–9 July, 2004, Hennessy works for CSIRO, Canberra.

Hennessy K.J., Page C., McInnes K., Jones R., Bathols D., Collins D. and Jones D. 2004, *Climate change in New South Wales– Part 1: Past climate variability and projected changes in average climate*, Consultancy report for the New South Wales Greenhouse Office by CSIRO Atmospheric Research and Australian Government Bureau of Meteorology: Canberra.

Hennessy K.J., Page C., McInnes K., Walsh K., Pittock B., Bathols J. and Suppiah R. 2004, *Climate change in the Northern Territory,* Consultancy report for the Northern Territory Department of Infrastructure, Planning and Environment by CSIRO Atmospheric Research Climate Impacts Group and Melbourne University School of Earth Sciences, published by the Northern Territory Government, Darwin.

Higginbottom K. 2003, *Nature–based tourism; productive or destructive for the environment?,* Wildlife Australia Magazine, Winter 2003.

Hillman, A. L. 2003, *Public Finance and Public Policy: Responsibilities and Limitations of Government,* Cambridge University Press: Cambridge.

Hobbins M.T. and Ramirewz J.A. 2004, *Trends in pan evaporation and actual evapotranspiration across the conterminous US: Paradoxical or complementary?*, Geophys.Res.Letters. 31, L13503.

Hollick, M. 1993, *An Introduction to Project Evaluation,* Longman Cheshire: Sydney.

Houghton N. and Styles E. 2002, *Future thinking: exploring future scenarios for climate change and effects on the National Highway System,* ARRB Transport Research Ltd., Vermont South: VIC.

House of Representatives Select Committee into the Recent Australian Bushfires 2003, *A Nation Charred: Report on the inquiry into bushfires,* House of Representatives Select Committee into the Recent Australian Bushfires: Commonwealth of Australia: Canberra.

Howden S.M., McKeon G. and Reyenga P. 1999, *Global Change Impacts on Australian Rangelands*, Working Paper. Series 99/09, CSIRO Wildlife and Ecology: Canberra.

Howden S.M., Lloyd–Smith H.A. and Crimp S. 2001, *Effect of climate and climate change on electricity demand in Australia,* Proceedings of the MODSIM 2001 international congress on modelling and simulation, The Australian National University Canberra, 10–13 December 2001.

Hughes, L. 2000, *Biological consequences of global warming: is the signal already apparent?*, Trends in Ecology and Evolution, 15, pp 56–61.

Hughes, L. 2003, *Climate change and Australia: Trends, projections and impacts*, Austral Ecology, 28, pp 423–443.

Indian Ocean Climate Initiative 2002, *Climate Variability and Change in Southwest Western Australi,* Indian Ocean Climate Initiative Panel, Indian Ocean Climate Initiative: Perth.

Insurance Council of Australia (IAG) 2003, *Submission to the House Committee into Recent Bushfires*.

Insurance Council of Australia (n.d.), *Flood Insurance Are You Covered?* available at www.ica.com.au

Insurance Disaster Response Organisation (IDRO), www.idro.com.au, accessed 28 July 2004.

Intergovernmental Panel on Climate Change (IPCC) (n.d.), *Special Report on Emission Scenarios,* A special report of Working Group III of the Intergovernmental Panel on Climate Change, World Meteorological Organisation and United Nations Environment Programme, Cambridge University Press: Cambridge.

IPCC 2001, *Third Assessment Report*, TS12.

IPCC (Houghton, J., Ding, Y., Griggs, D., Noguer, M., van der Linden, P. and Xiaosu, D., (eds)) 2001a, *Climate Change 2001: The Scientific Basis,* Contribution of the Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change. World Meteorological Organisation and United Nations Environment Programme, Intergovernmental Panel on Climate Change, Cambridge University Press: Cambridge.

IPCC (McCarthy J., Canziani O., Leary N., Dokken D and White K. (eds)) 2001b, *Climate Change 2001: Impacts, Adaptation and Vulnerability*, Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change, World Meteorological Organisation and United Nations Environment Programme, Cambridge University Press: Cambridge.

IPCC (Metz B., Davidson O., Swart R. and Pan J., (eds)) 2001c, *Climate Change 2001: Mitigation,* Contribution of Working Group III to the Third Assessment Report of the Intergovernmental Panel on Climate Change, World Meteorological Organisation and United Nations Environment Programme, Cambridge University Press: Cambridge.

IPCC 2001d, *Climate Change 2001: The Scientific Basis. Summary for Policymakers,* A report of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change, World Meteorological Organisation, Geneva: United Nations Environment Programme, IPPC: Nairobi.

IPCC 2002e, *Climate Change 2001. Synthesis Report,* Contributions of Working Groups I, II and III to the Third Assessment Report of the Intergovernmental Panel on Climate Change, World Meteorological Organisation and United Nations Environment Programme, Cambridge University Press: Cambridge.

IPCC 2004, *IPCC Expert Meeting on The Science to Address UNFCCC Article 2 including Key Vulnerabilities, Expert Meeting Report* IPPC: Buenos Aires, Argentina, 18–20 May 2004.

Jones R.N. 2001, *An Environmental Risk Assessment/Management Framework for Climate Change Impact Assessments*, Natural Hazards, vol 23.

Jones R.N. 2004, *Using Risk Assessment to Inform Adaptation, Workshop on Impacts of, and Vulnerability and Adaptation to, Climate Change,* Bonn.

Jorgenson D.W., Goettle R.J., Hurd B.H. and Smith J.B. 2004, *US Market Consequences of Global Climate Change* prepared for the Pew Center on Global Climate Change: Arlington.

Karoly D.J. and Braganza K. 2004, *Attribution of recent temperature changes in the Australian region*, Journal of Climate, In press.

Kleindorfer P.R and Kunreuther H. 2000, *Managing Catastrophe Risk.* Regulation, 23(4).

Kriticos D., Sutherst R., Brown J., Adkins S. and Maywald G. 2003, *Climate change and the potential distribution of an invasive alien plant: Acacia nilotica ssp. Indica in Australia*, Journal of Applied Ecology, vol. 40.

Kriticos D., Sutherst R., Brown J., Adkins S. and Maywald G. 2003a, *Climate change and biotic invasions: a case history of a tropical woody vine,* Biological Invasions, vol. 5.

Lambert F.G., Stott P.A., Allen M.R and Palmer M.A. 2004, *Detection and attribution of changes in 20th century land precipitation,* Geophys.Res.Letters, 31 L10203–6.

Love G., Langenkamp D. and Galeano D. 2004, *Seafood outlook to 2008–09.* Australian Commodities, vol 11, no 1.

Malcolm B., Sale P. and Egan A. 1996, *Agriculture in Australia* Oxford University Press: Melbourne.

Manne, A.S. and Richel, R.G. 2003, *Market exchange rates or purchasing power parity: does the choice make a difference to the climate debate?* Working Paper 03–11, September 2003, AEY–Brookings Centre for Regulatory Studies.

McKibbin W., Pearce D. and Stegman A. 2004, *Long run projections for climate change scenarios*, Working Papers in International Economics, No.1.04, p 66.

MDBC 2004, Land Degradation, found at http://www.mdbc.gov.au/education/encyclopedia/naturalresources/env_issues/land_degradation.htm#Table%205, accessed 6 August 2004.

Mills E., Lecomte E., and Peara A. 2001, *US Insurance Industry Perspectives on Climate Change* US Department of Energy: University of California: Berkeley.

Minmura N. 2004, *Past Findings and Future Discussions on Adaptation — Opportunities, Limitations and Barriers,* presented at PCC Expert Meeting on The Science Address UNFCCC Article 2 including Key Vulnerabilities.

Montgomery M. 2004, *The Mounting Infrastructure Challenge Facing Local Government,* address to National Infrastructure Summit: Melbourne, 16 August.

Moss R.H., Brenkert A.L., and Malone E.L. 2001, *Vulnerability to Climate Change: A Quantitative Approach.* prepared for the US Department of Energy, Pacific Northwest National Laboratory *operated by* BATTELLE: Springfield.

Murray Darling Basin Commission (MDBC) 2003, available at: http://www.mdbc.gov.au/river_murray/river_murray_system/river_murray_system.htm, accessed on 2 August 2004.

MDBC 2004, *Basin Statistics*, available at http://www.mdbc.gov.au/naturalresources/basin_stats/statistics.htm, accessed 6 August 2004.

MDBC 2004, *Land Degradation,* available at http://www.mdbc.gov.au/education/encyclopedia/naturalresources/env_issues/land_degradation.htm#Table%205, accessed 6 August 2004.

MDBC 1987, *Murray–Darling Basin Environmental Resources Study,* Murray–Darling Basin Ministerial Council: Canberra.

Musgrave R.A. and Musgrave P.B. 1982, *Public Finance in Theory and Practice,* 3rd edn. McGraw Hill: Sydney.

Nakicenovic N., Grübler A., Gaffin S., Jung T.T., Kram T., Morita T., Pitcher H., Riahi K., Schlesinger M., Shukla P.R., van Vuuren D., Davis G., Michaelis L., Swart R. and Victor, N. 2003, *IPCC SRES Revisited: A Response,* Energy and Environment, 14.

National Academy of Science 1992, *Policy Implications of Greenhouse Warming,* National Academy Press: Washington D.C.

National Committee on Coastal and Ocean Engineering 2004, *Guidelines for Responding to the Effects of Climate Change in Coastal and Ocean Engineering,* 2004 Update, Engineers Australia: Canberra.

National Land and Water Resources Audit 2001, *Australian Dryland Salinity Assessment: Extent, Impacts, Processes, Monitoring and Management Options,* Canberra.

National Land & Water Resources Audit 2001, available at http://www.rangelands–australia.com.au/ra_fset2.html.

National Museum of Australia 2003, *Can we Drought–Proof Australia?,* Canberra.

National Oceanic and Atmospheric Administration 2003, *Global surface temperatures over the past two millennia*, available at http://www.ngdc.mnoaa.gov/paleo9/pubs/mann2003b/mann2003b.html

National Research Council 2001, *Climate Change Science: An Analysis of Some Key Questions,* National Academy Press: Washington D.C.

National Water Initiative (n.d.), *National Water Initiative, Discussion Page*, http://www.pmc.gov.au/docs/national_water_initiative_progress.cfm, accessed 14 September 2004.

Nell M. and Richter A. 2004, *Catastrophe Events as Threats to Society: Private and Public Risk Management Strategie*s, Working Papers on Risk and Insurance, No. 12, January, Hamburg University.

Neumann J. von and Morgenstern O. 1944, *Theory of Games and Economic Behaviour,* Princeton University Press: Princeton.

NSW Treasury 1997, Guidelines for Financial Appraisal, Paper TPP 97–4.

Newell R. and Pizer W. 2001, *Discounting the Benefits of Cliamte Change Mitigation: How Much Do Uncertain Rates Increase Valuations?,* prepared for the Pew Center on Global Climate Change: Arlington.

Nicholls N. 2003, *Continued anomalous warming in Australia,* Geophys. Res. *Letters*, 30(7)*,* article 23.

Pant H. and Fisher B. 2004, *Comparison of real income across nations,* Proc. EMF Workshop on purchasing power parity and market exchange rates, Stanford University: Stanford, 19–20 Feb.

Pearman G.I., Hennessy K.J., Jones R.N. and Maheepala S. 2004, *Climate change and its projected effects,* Water–the Australian dilemma: speakers abstracts, Australian Academy of Technological Sciences and Engineering: Melbourne, pp 173–191.

Pindyck, R.S. 2000, *Irreversibilities and the Timing of Environmental Policy,* FEEM Working Paper no.5, http://papers.ssrn.com/sol3/papers.cfm?abstract_id=229009

Pingali P. 2004, *Climate Change and Food Systems*, IPCC Expert meeting on UNFCCC Article 2, Buenos Aires, 18–20 May 2004.

Pitman, A.J., Narisma, G.T., Pielke Sr, R.A. and Holbrook, N.J. 2004, *The impact of land cover change on the climate of south west Western Australia,* J.Geophys.Res.

Pittock B. (ed) 2003, *Climate Change: An Australian Guide to Science and Potential Impacts*, prepared for the Australian Greenhouse Office: Canberra.

Planning Institute of Australia Queensland Division 2002, *Climate Change and Sustainability Project: Overview of Research into Adaptation to Climate Change Through Planning,* Planning Institute of Australia (PIA) Queensland Division.

Planning Institute of Australia Queensland Division 2004, *Sustainable Regional and Urban Communities Adapting to Climate Change – Issues Paper,* PIA, June.

Powell R. and Chalmers L. 1995, *Regional economic impact: Gibraltar Range and Dorrigo National Parks*, prepared by the Centre for Agricultural and Resource Economics, The University of New England for NSW National Parks and Wildlife Service.

Preston B.L. (n.d.), *Probabilistic Risk Analysis of US Climate Change Impacts: Implications for Climate Policy,* Pew Centre on Global Climate Change: Arlington.

Public Private Partnership 2000, *The Uncertainties of Managing Catastrophic Risk*, Report on Second Forum, 11 December 1997.

Prime Minister's Science, Engineering and Innovation Council (PMSEIC) 1998, *Dryland Salinity and its Impacts on Rural Industries and the Landscape*, Canberra.

PMSEIC 1999, *Moving Forward in Natural Resource Management: The Contribution that Science, Engineering and Innovation can Make,* Canberra.

PMSEIC 2002, *Sustaining our Natural Systems and Biodiversity,* Canberra.

Queensland Environmental Protection Agency, http://www.epa.qld.gov.au/nature_conservation/wildlife/feral_animals/cane_toad/, accessed 14 September 2004.

Queensland Tourism 2002, *Fact Sheet — Tourism and the Economy,* Queensland Tourism.

Queensland Transport, CSIRO and PPK Infrastructure and Environment 1999, *The Effects of Climate Change on Transport Infrastructure in Regional Queensland*.

Rainforest CRC 2003, *Global Warming in the Wet Tropics: Issues in Tropical Rainforest Landscapes,* Issue 2.

Rangelands Australia website: available at http://www.rangelands–australia.com.au/ra_fset2.html

Reeves G., Quirke D., van Buern M., and Hanslow K. 2004, *Implications for Water Reforms for the National Economy,* prepared for the National Program for Sustainable Irrigation, Centre for International Economics, Canberra.

Reserve Bank of Australia 2002, *Economic Effects of the Drought in Statement on Monetary Policy,* Nov–02, *R*eserve Bank of Australia, Sydney.

Reserve Bank of Australia 2002, *Statement on Monetary Policy February 2002,* Reserve Bank of Australia, Sydney.

Roderick M.L. and Farquhar G.D. 2004, *Changes in Australian Pan Evaporation From 1970 to 2002,* International Journal of Climatology, 24: pp 1077–1090.

Ryten, J. 2004, *MERs PPPS and the IPCC: Illusions and reality,* Energy and Environment, 15, pp 363–367.

Sadler, B.S., Mauger, G.S., and Stokes, R.A. 1988, *'The Water Resource Implications of a Drying Climate in South–West Western Australia',* Greenhouse: Planning for Climate Change, CSIRO.

St Pius X College web site: http://www.spx.nsw.edu.au/src/Links/endanganim.html, accessed 20 September 2004.

Schneider S. 2004, www.stephenschneider.stanford.edu.

Schneider S.H. and Azar C. 2001, *Are Uncertainties in Climate and Energy Systems a Justification for Stronger Near term Mitigation Policies?,* prepared for the Pew Center on Global Climate Change: Arlington.

Schroter D. and the ATEAM consortium 2004, *Global change vulnerability — assessing the European human–environment system*, Potsdam Institute for Climate Impact Research.

Smith J.B. 2004, *A Synthesis of Potential Climate Change Impacts on the US,* prepared for the Pew Center on Global Climate Change, Arlington.

Stehlik D., Gray I. and Lawrence G. 1999, *Drought in the 1990s; Australian Farm Families Experiences,* Rural Social and Economic Research Centre, Queensland and Centre for Rural Social Research, NSW.

Steingold. M., Walker, G. 1999, AON Re *Sydney Hailstorm 14 April 1999: Impact on Insurance andReinsurance*, http://www.aon.com.au/pdf/reinsurance/Aon_Sydney_Hailstorm.pdf

Stott, P. 2003, *Attribution of regional–scale temperature changes to anthropogenic and natural causes,* Geophys.Res.Letters., pp 1729–31.

Sutherst R.W., Collyer B.S. and Yonow T. 2000, *The Vulnerability of Australian Horticulture to the Queensland Fruit Fly Under Climate Change,* Australian Journal of Agricultural Research, vol 51.

Sydney Morning Herald 2004, *World's Achilles Heels*, SMH 26/10/04.

Timbal B., and McAvaney B.J. 2001, *An analogue based method to downscale surface air temperature: Application for Australia*, Climate Dynamics., 17, pp 947–963.

Tindale, N. W., Derek N. and Fraser, P. J. (eds) 2003, *Baseline Atmospheric Program (Australia) 1999–2000,* edited by Bureau of Meteorology and CSIRO Atmospheric Research, Melbourne, Australia.

Thomas M.H. 2002, *Energy and Energy Intensive Industry, Proceedings, Living with Climate Change Conference*, National Academies Forum: Canberra, 19–Dec–02.

Thorne, P.W., Jones, P.D., Tett, S.F.B., Allen, M.R., Parker, D.E., Stott, P.A., Jones, G.S., Osborn, T.JU. and Davies, T.D. 2003, *Probable causes of late twentieth century tropospheric temperature trends,* Climate Dynamics, 21, pp 573–591.

UKCIP., Willows R.I. and Connell R.K. (eds) ., (2003). *Climate Adaptation: Risk, Uncertainty and Decision making — UKCIP Technical Report* UKCIP: Oxford.

Victorian Government 2004, *Adapting to Climate Change – Enhancing Victoria's Capacity*, Department of Sustainability and Environment: Melbourne, July, 2004.

Villach 1986, *The Role of Carbon Dioxide and Other Greenhouse Gases in Climate Variation and Associated Impacts*, Conference Statement for the Second UNEP/WMO/ICSU Assessment Meeting, Villach, WMO Bull: Austria 35, pp 130–134.

Walsh K., Cai W., Hennessy K., Jones R., McInnes K., Nguyen K., Page C. and Whetton P. 2004, *Climate change in Queensland under enhanced greenhouse conditions: Final report 1997–2002,* CSIRO Atmospheric Research consultancy report for the Queensland government, Aspendale.

Wentworth Group, The 2002, *Blueprint for a Living Continent: A Way Forward From The Wentworth Group of Concerned Scientists* Wentworth Group: Sydney, 1–Nov–02.

Wentworth Group, The 2003, *Blueprint for a National Water Plan,* Wentworth Group: Sydney, 31–Jul–03.

Whetton, P. 2001, *Climate change projections for Australia,* CSIRO Atmospheric Research: Canberra.

Whetton P., and Suppiah R. 2003, *Climate change projections and drought. Proc. National Drought Forum 2003: Science for Drought,* Queensland Department of Primary Industries: Brisbane, Apr–03, pp 130–136.

White N., Suthherst R.W., Hall N., and Whish–Wilson P. 2003, *The Vulnerability of the Australian Beef Industry to Impacts of the Cattle Tick Under Climate Change,* Climatic Change, 61(1–2): pp 157–190.

Wolff et al., *Nature* 429, pp 823–628.

World Bank 2003, *Global Economic Prospects and the Developing Countries 2003,* World Bank: Washington.