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National Climate Change Adaptation Research Plan
Human Health

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The role of the National Climate Change Adaptation Research Facility is to lead the research community in a national interdisciplinary effort to generate the information needed by decision-makers in government and in vulnerable sectors and communities to manage the risks of climate change impacts.

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National Climate Change Adaptation Research Plan

Human Health

Contents

Executive Summary

Climate change poses direct and indirect risks to health. Direct risks include physical injury because of more frequent events such as bushfire, and increased heat-related death and disease. Indirect risks include more infectious diseases transmitted through vectors such as insects, and mental and physical health difficulties that typically follow the social and economic disruption and dislocation caused by events such as drought.

The diversity of health risks from climate change presents a direct challenge to the health sector —including acute health care and the public health system. Many health-protecting activities will need to be undertaken by other sectors of government and industry, as well as by individuals and communities. In conjunction with Research Plans addressing other priority themes, this Plan will guide researchers generating the information that Australia needs in order to develop an effective and equitable portfolio of adaptation strategies.

Current state of research

Research on climate change and health—impacts, risks and adaptive strategies—has been limited. The topic is relatively new and complex; existing professional research capacity is low. Most research has focused on estimating future health impacts (as presented in the recent Garnaut Report). Few studies have yet explored differential vulnerability between populations based on location, age, wealth or other relevant indicators. Very few studies have assessed adaptive strategies.

Priorities for climate change-related health research

This Research Plan identifies key research questions within nine sub-themes of health-related adaptation research, relating to: heat, extreme weather events, vector-borne diseases, food safety and quality, air quality, water quality, mental health, community and Indigenous health, and health care services and infrastructure. To identify priorities within these nine sub-themes, the following principal criteria were used:

- severity of potential impact or degree of potential benefit;
- immediacy of required intervention or response;
- need to change current intervention or the practicality of intervention;

combined with these desirable criteria:

- potential for co-benefits;
- potential to address multiple, including cross-sectoral, issues;
- distribution and equity of the perceived benefits of any adaptation strategy.

Applying these criteria, the following priority research questions were identified from within the sub-themes listed above.

Priority research questions for Climate Change Adaptation and Human Health

Heat

- Which categories of people are most vulnerable to short-term extremes of heat?
  - Do levels of understanding of the nature of the risks, and personal/household-level ways of ameliorating them, vary between these population subgroups?
  - Are changes needed to public health policy in order to manage heat wave impacts?
- Do early warning systems (EWSs) for heat waves and other extreme weather events reduce the adverse health impacts?
  - Which types of EWS are most effective?

Extreme weather events

- Does public education about the risks of extreme events, and their avoidability, alter people's knowledge and behaviour?

Vector-borne disease

- What are the future increased risks of arbovirus diseases arising from climate change? This question should focus on population movements and changes in northern Australia, and the monitoring of potential vectors.
  - Does climate-driven predictive modelling of any particular vector-borne infectious disease outbreak reduce the occurrence of such outbreaks?
  - How would existing public health systems cope with increased levels of vector-borne disease (VBD) infections?
- Can meteorological forecasts of impending seasonal weather conditions provide useful advance warning of altered risks of vector-borne infectious disease outbreaks? Does such usefulness differ between human-only and zoonotic VBDs?
  - Are such forecasts enhanced by the inclusion of information about changes in environmental indicators (e.g., surface water conditions, vegetation levels, etc)?
  - Will the implementation of such early warning systems result in reductions in outbreaks or infection rates?

Food, air and water quality

- Where will the likely climate change impacts on food safety and quality be observed, and what measures/practices can be implemented to reduce the risk of food-borne disease outbreaks?
- What is the role of water authorities responsible for treating water in the management of climate change impacts?

Mental health

- What interventions are required to minimise the potential adverse mental health effects of natural disasters (such as drought, windstorms and floods)? Initiatives to address this question should build on the established models and frameworks in disaster mental health planning.

Community and Indigenous health

- How might climate change and changes in the occurrence of extreme events affect aspects of Indigenous culture and living conditions that affect health?
- Which types of intervention most effectively increase the level of community resilience?
  - What key characteristics of Indigenous, rural and urban communities determine the level of resilience of these communities to the stress of long-term changes in climatic and environmental conditions?

Health services and infrastructure

- What models of integrating the entire health sector's adaptive responses best support the coordination of adaptive activities?
- What models of linkage and knowledge exchange between climate change researchers and policy-makers best provide relevant decision support in planning health sector responses?
- What role should the primary health care sector play as part of a broader public health adaptive response to climate change?
- Is the health care system adequately structured and staffed to handle increased demands from (i) extreme weather events and (ii) outbreaks of infectious diseases?
  - What improvements are needed, feasible and effective?
- What forms of in-career training of health care professionals best prepare them to identify and respond to climate-related health impacts?

1. Background

1.1 Context and objectives of the National Climate Change Adaptation Research Plan for Human Health

This National Climate Change Adaptation Research Plan (NARP) for Human Health sets out the research priorities for health research over the next 5–7 years. It is a guide to researchers, to potential funders, and to potential users of the research, including policy-makers, managers and service providers throughout the Australian health services.

The National Climate Change Adaptation Framework ('the Framework') was endorsed by the Council of Australian Governments (COAG) in April 2007 as the basis for government action on adaptation over 5–7 years. The Framework includes possible actions to assist vulnerable sectors and regions to adapt to the impacts of climate change. It also includes actions to enhance the knowledge base underpinning climate change adaptation.

In 2007, the Australian Government committed $117 million over 5 years towards implementing the Framework. As part of this investment, the Australian Government established the National Climate Change Adaptation Research Facility (NCCARF, based at Griffith University) to coordinate and lead the Australian research community in generating the biophysical, social and economic information needed to adapt to climate change. Up to $30 million will be invested in priority research for key sectors, as identified in National Climate Change Adaptation Research Plans, giving effect to Action 1.1 of the Framework, which aims to improve national coordination of climate change adaptation research. The Plans are being progressively developed by the Facility in partnership with governments, stakeholders and researchers; they will set national priorities for adaptation research. The Plans will be important tools for coordinating adaptation research across Australia and will be implemented by the NCCARF with assistance from the adaptation research networks and through the participation of all Australian jurisdictions.

The main purpose of the NARP for Human Health is to articulate the research agenda for the next 5–7 years through which to acquire a fuller understanding of the health risks from climate change in Australia, and how to reduce those risks via planned adaptive interventions. Implementation of the Research Plan will contribute to an improved understanding of the range of current and anticipated risks to health from climate change, estimates of the likely resultant burdens of poor health, an understanding of differential vulnerabilities within the population, and agreement on the relevant criteria for assigning priorities in the choice of adaptive strategies. Implementation should not take place in isolation: coordination across related thematic areas should contribute to the development of an effective and equitable portfolio of adaptive strategies.

Recognition of risks to health, and appreciation of the possibilities for reducing those risks, is at this stage a topic that is generally unfamiliar to most segments of our society. Governmental agencies, community organisations, the research community and the private sector have not previously paid much attention to the issue of risks to health from climate change, let alone the potential for adaptation. The Plan will therefore also provide a stimulus to future thinking about how best to study and reduce the risks to health, especially how to include some consideration of the protection of population health dimensions in policy developments, and adaptive strategies within other sectors.

The main purpose of the NARP for Human Health is to articulate the research agenda for the next 5–7 years through which to acquire a fuller understanding of the health risks from climate change in Australia, and how to reduce those risks via planned adaptive interventions.

1.2 Climate change and society's responses

The Fourth Assessment Report of the United Nations Intergovernmental Panel on Climate Change (IPCC) concluded that global average surface temperatures have increased by 0.74°C (0.56°C–0.92°C) over the past century, and that warming is unequivocal, with most of the warming of the past 50 years being very likely (90%) to be due to increases in greenhouse gases (IPCC, 2007a). The Report also noted that most of the past century's warming has occurred in the most recent three decades, and that there is at least that much additional latent (unrealised) warming already built into the climate system, no matter what mitigation action is taken (IPCC, 2007a). The Report projects that global average surface temperature will increase by between 1.1°C and 6.4°C over 1990 levels by 2100, with a generalised increase in variability in weather patterns and the occurrence of extreme events.

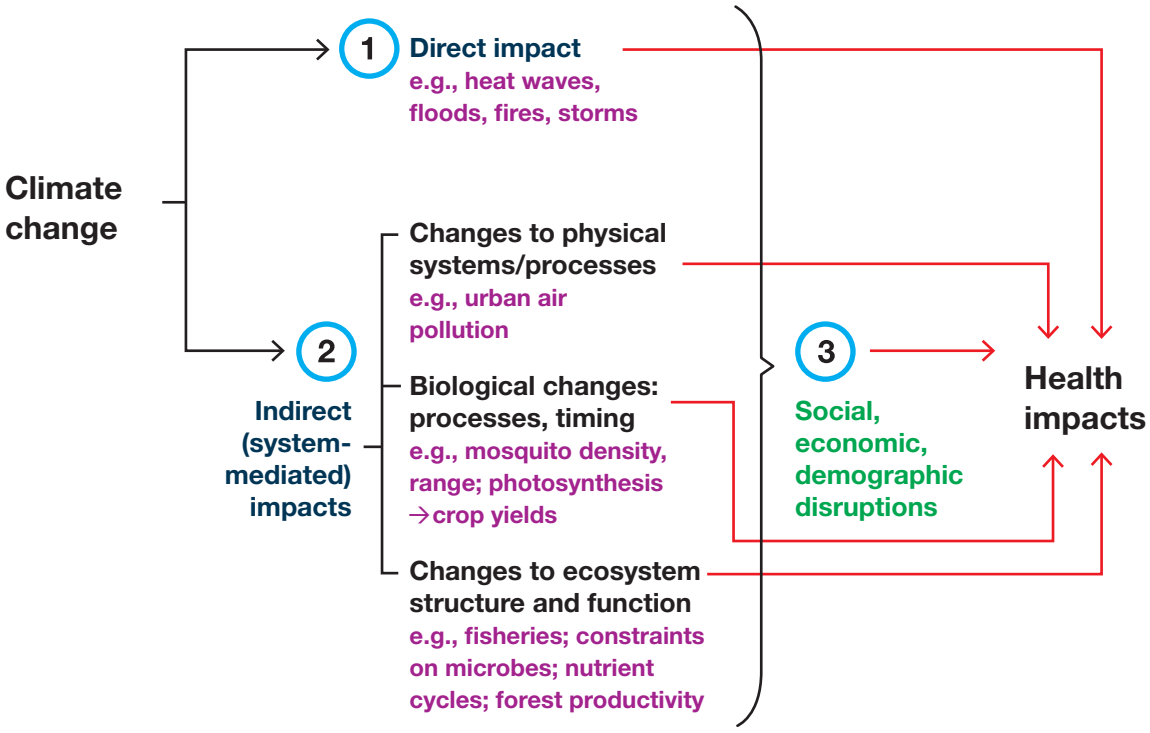
There are two main features of climate change response policy. *Mitigation* is the reduction of greenhouse gas emissions through the use of technology and substitution in order to reduce resource inputs and emissions per unit output (IPCC, 2007c). *Adaptation* is the 'adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities' (IPCC, 2007b). While mitigation seeks to avoid the unmanageable (i.e., 'dangerous climate change'), adaptation seeks to manage the unavoidable (i.e., existing and pending risks). Mitigation is the first-order business at local, national and international levels. Adaptive strategies are also needed, on a broad front, to lessen the actual adverse impacts of climate change now and in the foreseeable future. Unless international cooperation and the level of mitigation actions increase, that need will extend into the longer-term future. Such an extended reliance on adaptation — particularly if substituted for mitigation — would heighten the moral dilemma posed by climate change, since adaptation will generally be more achievable and affordable in high-income countries.

It should be noted that mitigation actions may well produce their own indirect health effects, both positive and negative. Reduced reliance on private motor vehicles, for example, may enhance fitness and overall individual health. This National Climate Change Adaptation Research Plan for Human Health therefore proceeds from the assumption that adaptation and mitigation are both essential and complementary elements of the social response to climate change.

1.3 Risks to health from climate change

Climate change poses diverse risks to health (Confalonieri et al., 2007; McMichael et al., 2006). Some health impacts will occur by direct-acting pathways, via physical injury and thermal extremes. Others will occur via climatic influences on complex ecological, biological and social systems. This includes, for example, changes in the risks of infectious disease transmission, food yields, and—via even more extended pathways—the various mental and physical health risks that typically follow social and economic disruption and dislocation (see Figure 1). Both the mean monthly/annual temperature (and hence the absolute distribution of daily/weekly temperatures) and the pattern of short-term temperature variability will shift under climate change. This will have varying effects on risks (both increases and decreases) across the full range of temperatures experienced. Various forms of spontaneous adaptation will occur that will modulate such changes in risks. While the impacts of extremes of temperature are of the greatest concern, studies of adaptation and adaptation strategies should consider the totality of impacts.

Figure 1. Potential ways in which climate change can impact on human health.



The main health risks represented in Figure 1 derive from:

- heat waves;
- extreme weather events/disasters;
- vector-borne infectious diseases;
- effects on air quality and aeroallergens, plus the (biological) interaction of some air pollutants with meteorological conditions;
- environmental infectious diseases—water- and food-borne;
- altered food production, affecting yields and nutritional quality;
- social, economic and demographic dislocation (especially in relation to mental health).

These are outlined in more detail in Table 1. The effects of climate change on human health and the best mix of adaptation strategies will vary across Australia, both geographically and across socio-economic and cultural groups. Understanding the risks and devising appropriate adaptation strategies will need to take into account current and future demographic trends. While this Plan seeks to identify national research priorities, local- and regional-level studies will also be essential to ensure the effectiveness of public health interventions.

Table 1. Major issues for adaptation in relation to health risks

Environmental effects

Extreme events

- cyclones/storms/floods
- bushfires
- drought
- heat—both heat waves and increases in temperature and/or humidity over time

Changes in natural systems

- Water
  - supply
  - quality—monitoring
  - water-borne diseases, environmental pathogens—surveillance, outbreak control
- Air
  - quality—monitoring; forecasting (short and long term)
  - pollution control and monitoring (especially for respiratory illness)
  - respiratory diseases—surveillance
  - UV exposure
  - emission control to maintain air quality
- Vector-borne (and zoonotic) diseases
  - monitoring, early warning systems
  - outbreak control
- Food-producing systems
  - food safety
  - quality
  - supply, seasonality, variety and cost

Impacts on community/social environment

- Lifestyle impacts/social dislocation
- Impact on determinants of mental health
- Adverse community effects

Infrastructure and services

- Essential services
  - coping capacity of hospitals etc.
  - urban and building design (e.g., the 'urban heat island' effect)
  - disaster preparedness
- Economic
  - cost–benefit analysis of adaptive strategies
- Evaluation of adaptive strategies
- Health data systems

1.4 Stakeholders' issues

Human health touches on, and is influenced by, a very wide range of factors. This is reflected in the equally wide range of institutions, organisations, groups and key individuals who have an interest in human health. Accordingly, the NARP (Human Health) needs to be sensitive to the breadth and diversity of interests and must give careful attention to the identification and management of stakeholders. These stakeholders fall into three categories:

1. those who will advise on, shape, or conduct research (e.g., universities, research institutions, consultants, government agencies);
2. those who will provide resources and/or funding for the research (e.g., state and federal governments, NHMRC, charities, philanthropies; *pro bono* contributors);
3. those who will use or disseminate the results of research whether to the wider community, or to smaller, targeted groups of people (e.g., government agencies, community groups, physicians, local councils).

For the purposes of this NARP, the term 'stakeholders' refers principally to the second and third groups—those who will use and fund priority research. Discussions with representative major stakeholders were conducted in a workshop held in March 2008. Stakeholders have raised a number of issues and topics that they consider to be important, and these ideas helped frame the research agenda for the NARP. The needs and requirements of the stakeholders can be outlined as follows:

- to communicate to the wider community (and specific vulnerable groups within it) that the risk to health posed by climate change impacts is real (i.e., to ensure that they perceive the issue as important), in order to encourage the community to take action;
- inclusion in any consultation regarding the posing of research questions, and the framing of the research program;
- inclusion in the conducting of recommended research, and access to the data used and/or generated by this research;

Two main issues raised by stakeholders in relation to framing appropriate research questions were (i) the need for communication between researchers and stakeholders in addressing local needs in research (as opposed to national/state-level needs); and (ii) wherever possible, for the research and adaptive strategies to be proactive rather than reactive.

- to ensure that the results of the recommended research are communicated effectively and in a timely manner to the wider community, or to specific, vulnerable, target groups within the community.

Two main issues raised by stakeholders in relation to framing appropriate research questions were (i) the need for communication between researchers and stakeholders in addressing local needs in research (as opposed to national/state-level needs); and (ii) wherever possible, for the research and adaptive strategies to be proactive rather than reactive.

It is essential that research teams build—and maintain over the long term—cooperative, productive and trusting relationships with key policy institutions and influential individuals. Effective stakeholder engagement and management will enable the research effort as a whole to be inclusive of all relevant issues and to build relationships that will support the research, the dissemination of findings and, crucially, a policy decision-making process that is cognisant of research findings.

New knowledge generated by research is more likely to find its way into the policy debate if the policy-makers and their teams have been part of the research. For this reason, a key strategy for research teams will be to include representatives of key stakeholder groups—particularly policy-makers—in research projects from the outset.

A South Melbourne beach in the heatwave of January 2009. Image: Newspix/Mark Smith.

1.5 Links and synergies to other Research Plans

A number of other National Climate Change Adaptation Research Plans are being developed to address the need for climate change-related adaptation research in a range of sectors. In some instances, the research and recommendations contained in the Human Health Plan will interact with the other Research Plans, and vice versa. Some examples of direct interactions are shown below. Indirectly, the wider community may benef t from the proposed research and adaptive strategies listed in this Plan, thus reducing disability-adjusted life years (DALYs) caused by health problems attributed to climate change. This will enable other sectors and industries to function at an optimal level of productivity.

Terrestrial biodiversity

Climate change-related increased acidity or salinity of soils and patterns of regeneration of natural vegetation may alter patterns of distribution for vectors and hosts of disease, in turn affecting human health. Rats are one example: both introduced and native rats can harbour the causative bacteria for the potentially fatal disease leptospirosis; variation in rainfall may force rats closer to human habitation, resulting in an increased chance of infection by *Leptospira*.

Primary industries

The nexus between the primary industry and human health sectors is the ability to produce suff cient good-quality food. Good nutrition is essential throughout all stages of life to protect against illness and disease, and is especially important for growth and maturation in infancy and childhood. Changes to food availability and pricing as a result of climatic change will have an impact on nutrition.

Water resources and freshwater biodiversity

Access to clean water supplies is an important aspect of improving health and preventing illness. and climate change has the potential to affect the security of this access.

Marine biodiversity and resources

The links between marine biodiversity and human health are subtle. Decreasing biodiversity may impact unfavourably on food production (i.e., f sheries), particularly if the food web is affected and species once considered to be abundant for food become scarce. This may have a more profound health effect on particular groups for whom f sh and seafood are fundamental to their social and nutritional needs.

Settlements and infrastructure

Important synergies exist with human health; for example, can the current hospital systems in our cities and towns cope with the inf uxes of patients injured or made unwell by heat waves, storms and infectious diseases, or suffering from mental health problems attributed to changes in climate? Adaptation strategies that will impact positively on human health include changes in building codes, actions to reduce heat islands (such as tree planting), and improvements in housing design.

Emergency management

The projected increase in extreme weather events means that emergency services may have to cope with more people displaced or injured in extreme events. Management of the aftermath of natural disasters or extreme climatic events will be imperative to ensure that the affected community remains healthy.

Social, economic and institutional dimensions

The synergies between human health and social environment are strong, particularly for rural and Indigenous communities, where health care will need to be specialised. A strong, resilient community is more likely to remain healthy despite adversity. It is also true that healthy communities are more likely to work together to implement adaptive strategies.

2. Categories and examples of adaptation

Adaptation can be both spontaneous (autonomous) and planned (deliberate) (Ebi et al., 2005). Most of the research agenda will focus on planned adaptation comprising actions taken by various components of society in order to reduce the health risks posed by climate change. Some planned adaptations entail the improvement or extension of existing policies and social functions; others will require innovative thinking and action.

2.1 Spontaneous adaptation

While the principal focus of the research agenda will be on information requirements to assist in adaptation planning, spontaneous adaptations need to be understood for at least three reasons. First, spontaneously occurring changes may pre-empt some or all of the anticipated benefits of a particular planned adaptive strategy. Second, if such spontaneous adaptive changes can be quantified and then included in scenario-based modelling of future health risks, the net change in future risk will be better estimated. Third, where spontaneous adaptation actions could undermine mitigation efforts or have adverse environmental impacts, planned interventions will need to take account of this risk.

A good example is the need to understand how populations will adapt, physiologically and behaviourally, to increases in temperature and in the frequency of very hot periods. A spontaneous adaptive reaction to heat may be that more people buy air-conditioners. Any such adaptation will modify the population's vulnerability to future increases in thermal stressors. Similarly, another spontaneous adaptation with potentially positive health effects is the increased use of household insecticides around homes and gardens in response to outbreaks of arbovirus diseases (although this may carry a different set of potential health risks). The potential influence of such spontaneous adaptations highlights the need for systems-based approaches to adaptation research and planning.

2.2 Planned adaptation

Planned adaptation may be the result of government policy, professional intervention, or local community initiative and action. Such adaptation may be implemented at one or more levels of society, from individual, through family and community, to state and national governments.

Some adaptation strategies will entail the improvement or extension of existing policies and practices. Others will require innovative actions. Many will require coordinated action across diverse sectors of government and community activity, extending far beyond the conventional health sector. Adaptation strategies are likely to occur in the short, medium and long term, and research priorities need to reflect these differing time-frames.

Climate change is unlikely to cause entirely new diseases.[1] Rather, climate change will alter the incidence, temporal pattern, range and seasonality of many existing health disorders. These include the severity of heat wave impacts, mental health stresses in farming communities, and the geographical range of some infectious diseases (see Appendices 1 and 2 for examples). These disorders are already affected by significant demographic trends, such as the ageing and urbanising population. Therefore, the existing health care and public health systems should provide an appropriate starting point for strengthening adaptive strategies to lessen these already familiar health impacts. In addition, there is a need for heightened awareness, appropriate workforce training, and greater engagement by the formal health sector. The latter includes the important task of achieving greater cross-linkage with other sectors engaged in responding to climate change in order to ensure that the criterion of health protection is integrated into planning and policy across a broad front.

1 It is possible that climate change could contribute to the emergence of some new human infections from novel, probably zoonotic, viruses and other microbes—for example by affecting patterns of bird migration and bat and mosquito dispersal and/or contact between wildlife and humans.

3. Current state of research on health impacts, vulnerability, and adaptive strategies

3.1 Overview

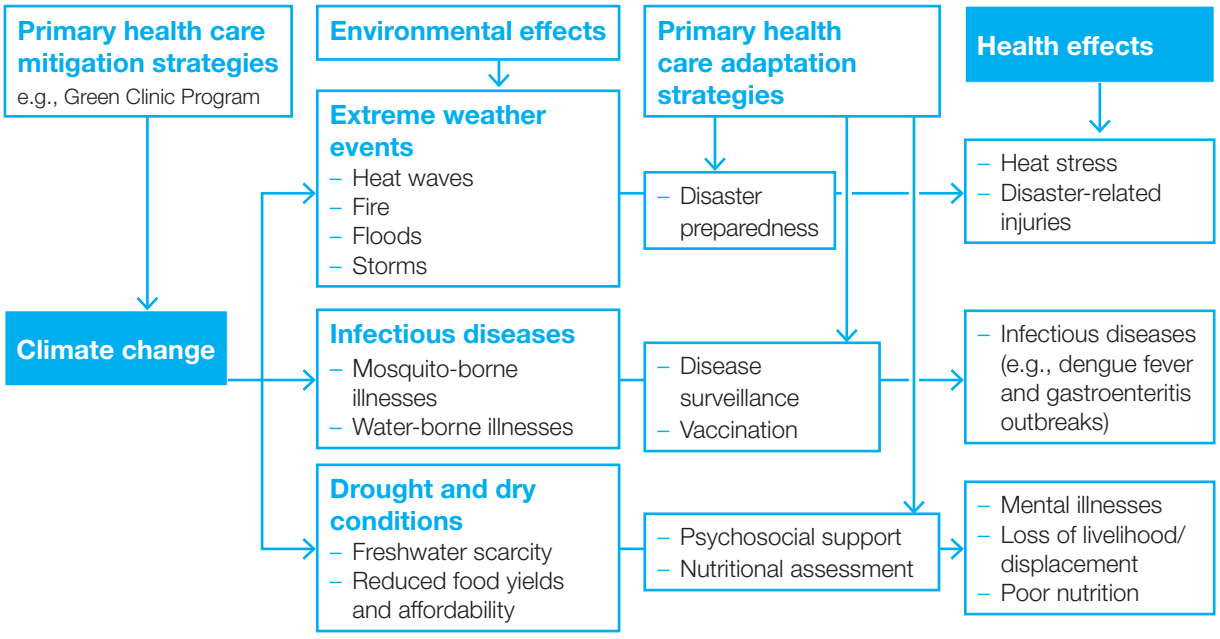
Climate change presents a direct challenge to the health sector—including acute health care and the formal public health systems. Climate change has the potential to cause shifts in priority for many aspects of health and health care; so adaptation to the risks and impacts on health caused by climate change is a high-priority area for research.

The public health system works towards promoting physical and mental health and preventing disease, injury and disability. Several of the long-established public health interventions, such as weather alerts, mosquito control and vaccination programs, should provide an effective starting point for adaptive strategies to reduce climate change-related morbidity and mortality (Frumkin and McMichael, 2008). Such adaptive interventions can be framed in relation to the three traditional pillars of public health prevention: primary (reduce climate change-related exposures); secondary (reduce the onset or slow the progression of climate change-related health impacts); and tertiary prevention (treat and manage the health impacts that cannot be prevented).

As an example, primary prevention in relation to the adverse health outcomes of heat waves would reduce or eliminate the 'exposure' of people to thermal stress. Secondary prevention would identify those at particular risk of adverse health impacts, such as people with underlying cardiovascular disease, and would provide appropriate advice, cooling approaches and treatment. Tertiary prevention would provide post-event support, treatment and advice to those who experience adverse health consequences. These preventive measures need to work together, not against each other.

Such interventions are conventionally seen as the responsibility of national and state public health agencies. However, the full spectrum of

Figure 2. Adaptive strategies: opportunities for intervention via the primary health care system (from Blashki et al., 2007).



climate-related risks to health is very wide, and many health-protecting activities will need to be undertaken by other sectors of government and industry, as well as by individuals and communities.

Primary health care is an important component of the overall health system's adaptive response, because primary health care systems provide a broad range of services including physical, psychological and social health care, and include the concept of prevention as well as treatment adapted to local conditions (Figure 2). The critical role of primary health care in addressing climate change adaptation issues highlights the need to enhance the capacity of the system, especially in areas of recognised capacity limitations, such as Indigenous communities.

Important points to consider:

- Participation in public education and awareness
- Early alert systems: impending weather and air pollution extremes, infectious disease outbreaks
- Disaster preparedness, including increasing the health system's 'surge' capacity to respond to emergencies
- Enhanced infectious disease control programs
  - food safety, vaccine programs, vector control, case detection and treatment
- Improved surveillance
  - risk indicators (e.g., population heat exposure profiles, mosquito numbers, aeroallergen concentrations)
  - health outcomes (e.g., infectious disease outbreaks, rural suicides, asthma peaks)
- Appropriate health workforce training, including mid-career development (e.g., updated understanding of climatic influences on health, training in public health and occupational health).

Despite the potential impact on the health sector, research in Australia into this spectrum of topics has been rather limited to date. Key research areas that need addressing include understanding how climatic variation and change affect specified health outcomes; identifying which groups or population segments are most vulnerable; and identifying and evaluating the effectiveness of adaptive strategies.

Research across this spectrum is relatively new and complex, and existing professional research capacity is low, especially compared with other fields of climate change science and research. This is broadly in line with the situation in other developed countries (such as the USA, Canada, the UK and other European countries); however, Australia has been somewhat slower to recognise the importance of this topic area and to mobilise research resources and funding.

In order to propose, implement and evaluate adaptive strategies to reduce risks to human health, 'adaptation research' should necessarily encompass studies that clarify and quantify current and estimable future risks (including modelling future scenario-based risks); explore the distribution and determinants of differential vulnerability to those risks; and evaluate the efficacy (including cost-effectiveness) of adaptive strategies—including the assessment of any unintended (collateral) impacts on health.

The research on adaptive strategies will need to encompass three main approaches:

1. consideration of general principles and methodological challenges in relation to adaptation measures (e.g., the role of experimentation and of simulation modelling for interventions with anticipated delayed or slowly accruing health benefits);
2. estimation of the extent and distribution of health-protecting benefits from adaptation strategies;
3. clarification of criteria, principles and methods for the evaluation of adaptation strategies.

3.2 Existing knowledge from published research

Most of the research on climate change and health in Australia over the past decade has focused on empirical studies of climate–health relationships and, via modelling, the estimation of future health risks. Research into the role of primary health care as an adaptive response to climate change is very limited—it is a new field, the analytic methodologies are not sufficiently developed, and the current data regarding climate change-related health impacts are insufficiently refined, both spatially and temporally. Existing literature in Australia, Canada and the UK is mostly descriptive and makes assumptions and inferences based on non-primary health care data and broad-brush climate-related health risks. Emerging priority areas for future research include: identification of risk by region; preparedness of local primary health care services and occupational health services; and integration of climate-related health data across primary, secondary and tertiary health services.

Few studies have yet explored issues relating to differential vulnerability, and even fewer have assessed adaptive strategies. There has, however, been research conducted on climate change and health in Australia concerning heat as an occupational health hazard and an impediment to sports achievements. The engagement of experienced Australian ergonomists and physiologists in the climate change and health area will substantially strengthen future research.

Western Australia and Victoria have both produced reports outlining the risk of health impacts caused by climate change, and adaptation strategies, relevant to their state (see Carey, 2007; Spickett et al., 2008). Similarly, a number of reports published by the Australian government include overviews of the health impacts of climate change (see, for example, Allen Consulting Group, 2005; Pittock, 2003). These reports highlight the importance of understanding the potential health impacts of climate change and how these impacts can affect communities. They also provide information on issues requiring further research, and the development of planning to enable communities to adapt.

There have been studies of the following topics relating to climate change-related health impacts and risks in Australia (approximate number of *published* papers shown in brackets):

- The relationship between very hot spells (especially heat waves) and health outcomes—deaths, hospitalisations, ambulance call-outs. This has included some studies of the possible interactions between temperature and air pollution (the latter itself, in part, being influenced by meteorological conditions). This research has been confined to capital city populations (*n* = ~8).

January 16, 2007: A premature baby at a Melbourne hospital is cooled by a fan during a heatwave. Image: Newspix/Cameron Tandy.

Most of the research on climate change and health in Australia over the past decade has focused on empirical studies of climate–health relationships and, via modelling, the estimation of future health risks.

- Initial explorations of how climatic variations relate to patterns of occurrence of asthma—likely effects of temperature and rainfall on growth and release of aeroallergens (n = ~5).
- Relationships between weekly and monthly temperatures and the rates of reported cases of major categories of gastroenteritis—especially caused by *Salmonella* and *Campylobacter* (n = ~3).
- The role played by climatic factors—temperature, rainfall, tide heights, etc—in the patterns of occurrence of several major vector-borne infectious diseases in Australia: especially Ross River virus (studies in Northern Territory, Western Australia, Queensland and New South Wales) (n = 13). There have also been isolated studies on Murray Valley encephalitis and Barmah Forest virus (n = ~1).
- How annual rainfall levels in New South Wales relate to annual suicide rates. That work is being pursued at higher resolution in order to differentiate between urban and rural relationships (n = ~1).

There have also been studies on the relationships between the full range of daily temperatures and health outcomes (again in capital city populations); e.g., recent research done at the National Centre for Epidemiology and Population Health (NCEPH) for the *Garnaut Climate Change Review* (2007–2008) (Garnaut, 2008). This work estimated net changes in annual mortality, by age group, in response to current distributions of daily temperatures, and applied this to future scenarios of temperature distributions. There have also been several studies using scenario-based modelling to estimate the future health risks in Australia for selected health outcomes, including the following three sets of analyses (coordinated by NCEPH).

- A 2002 study, commissioned by the Australian Government Department of Health, to estimate the future (2030, 2070) risks of deaths from heat waves, of transmission of dengue fever and malaria, and of diarrhoeal disease in Aboriginal communities in Central Australia, and of deaths and injuries from flooding (McMichael et al., 2003).
- A 2005 study, commissioned by the Australian Medical Association and the Australian Conservation Foundation to repeat a similar set of analyses as above, but for a different set of climate change scenarios, and extending to 2100 (Woodruff et al., 2005).
- Commissioned research (as input to the Garnaut Report) into estimating the future health impacts and associated economic costs, for updated climate change scenarios across the 21st century, for temperature effects on deaths and hospitalisations, transmission risks of dengue fever, gastroenteritis (especially salmonellosis), and (in semi-quantitative fashion) Ross River virus disease, and mental health impacts in rural Australia (unpublished).

Emerging priority areas for future research include: identification of risk by region; preparedness of local primary health care services and occupational health services; and integration of climate-related health data across primary, secondary and tertiary health services.

4. Climate change-related research in Australia: current knowledge, gaps and research priorities

This discussion of the current state of health impacts research in Australia is organised around nine areas: heat, extreme weather events, vector-borne diseases, food safety and quality, air quality, water quality, mental health, community and Indigenous health, and health care services and infrastructure. The assessment is not intended to be exhaustive. Rather, it is hoped that the list can inform the current state of health and climate change research in Australia, in order to improve and direct future research.

4.1 Heat

4.1.1 Current knowledge and gaps

The Australian average annual mean temperature has increased by 0.9°C since 1950. The frequency of hot nights has increased, while the frequency of cold nights has declined (Alexander et al., 2007; CSIRO and BoM 2007). The best estimate of annual warming over Australia by 2030 is around 1.0°C, with warming of around 0.7–0.9°C in coastal areas and 1–1.2°C inland. Associated with the warming is a projected strong increase in frequency of hot days and warm nights (CSIRO and BoM, 2007).

The increase in extreme heat events is projected to increase the number of heat-related deaths. Heat-related deaths in the major capital cities combined (Adelaide, Perth, Melbourne, Sydney and Brisbane) are predicted to increase from 1,115 per year (1997–1999) to 2,300–2,500 per year by 2020 (McMichael et al., 2003). Taking into consideration changes in population and age demographics, a temperature increase of 1.64°C over 1990 levels could increase heat-related deaths in Brisbane from the current estimated 134 per year to over 1,000 deaths per year by 2050 (McMichael et al., 2003). Mortality predictions sit at the extreme end of the impact scale but foreshadow the increase in minor heat-related health problems that will lead to increased hospitalisation, reduced quality of life, and loss of productivity. Heat particularly affects the elderly and infirm. Woodruff et al. (2005) have predicted a steep increase in heat-related deaths in people aged over 65 by the end of this century.

A number of studies have been conducted on heat-related morbidity and mortality during heat events. Kovats and Hajat (2008) listed a number of factors that are contributing determinants of morbidity and mortality during heat waves, based on data from the 2003 European heat wave. They are:

- age—the elderly and very young are more likely to be affected by the heat;
- those living in institutions (e.g., nursing homes);
- characteristics of housing and presence of air-conditioning;
- urban heat islands;
- socio-economic factors.

Other studies found a range of potentially conflicting results including:

- vulnerability to heat can increase despite a higher prevalence of air-conditioning and public health interventions (Smoyer, 1998);
- changes in public preparedness and public health responses may reduce morbidity and mortality during heat events (Weisskopf et al., 2002);
- the duration of the heat wave and the level of air pollution can affect health, but increased public awareness of heat can reduce vulnerability (Tan et al., 2007);
- increased awareness of risk from heat and knowledge of health management during heat events can contribute to lower mortality (Fouillet et al., 2008).

Temporal and spatial predictions for heat-related health impacts

Little research has been done in Australia to assess the impact of heat events on population health and to evaluate intervention programs. Recent research (Nitschke et al., 2007) suggests that, in contrast with results in the Northern Hemisphere, there was no excess mortality observed in Adelaide during recent heat events. The projected increases in temperature, however, may change this scenario, and the authors recommend that a heat event response plan be implemented in Adelaide. Recently, research has been conducted to determine whether there was an excess of deaths, and the relative role of temperature and air pollution,

during the 2004 heat wave in Brisbane (S. Tong, personal communication, 2008). Temperature appeared to have played a relatively more important role than air pollution.

It may be possible to reduce heat-related morbidity and mortality through a community development plan that communicates messages about coping with heat. Indeed, response plans and action plans for heat events have recently been implemented in a number of states. Such plans could include (from Kovats and Koppe, 2005; G. Lloyd, personal communication, 2008):

- early warning systems;
- local adaptive strategies, such as local councils ensuring that they have community facilities, which are kept cool, where people can seek refuge during hot weather; and air-conditioning for buses and trains (although the health benefits of the increased use of air-conditioners needs to be weighed carefully against their energy consumption);
- taking appropriate public health messages out to the wider community;
- strategies for ensuring that vulnerable or isolated people are checked on at times of heat extremes. Innovative approaches may be possible that respect the dignity of such individuals, for example the use of wireless communication devices which automatically notify most recent usage.

Early warning systems

A range of early warning systems (EWSs) in relation to impending climatic variations and events have been applied in various countries in diverse fields such as agriculture, heat wave impacts, and natural disasters. In general, the purpose of such systems is to provide advance warning, and hence to reduce vulnerability and increase preparedness (WHO, 2004). The development and use of short-term predictive models to provide early warning is now beginning to attract some research attention in epidemiology and public health—especially in regard to anticipated extremes of temperature and to anticipated outbreaks of infectious diseases.[2]

Warning systems exist in Australia for floods, cyclones and bushfires, but not for heat waves, which kill more people than the other events. The annual numbers of hot days (and hot nights) has been increasing since the 1960s. Some of the most recent research on heat alert systems comes from Australia, where Nicholls et al. (2008) have developed a model for a heat alert system for Melbourne. In addition, the Bureau of Meteorology is currently developing a heat wave warning system. Health-related thresholds for defining and declaring a heat wave are required, but this will vary by jurisdiction. Thresholds will be affected by coexistent exposures, such as to bushfire smoke and other air pollutants.

Rudimentary action plans in response to heat waves are now in place; for example, in Victoria and South Australia, where ambulance services mobilise more staff on hot days.

Heat effects on workforce productivity

The impacts of heat exposure (a combination of temperature, humidity, radiated heat and wind speed) on working people can be an important health hazard as well as an impediment to productivity (Kjellstrom, 2000; Parsons, 2003). There are physiological limitations to the human body's capacity to cope with high levels of heat exposure that overwhelm bodily cooling ability (via sweating and heat transfer to the immediate environment outside the skin). Such limitations mean that, during hot weather in many parts of Australia, additional cooling, or reduction of daily physical activities (including work) is necessary. The basic physiology at the individual level is well known, and expertise is available in Australia, but the implications of environmental warming due to climate change have not been studied.

This is an important issue for occupational health, as the need to protect workers against serious heat stress is becoming increasingly common, and spontaneous adaptation by slowing down the pace of working will impact on workers' productivity and, through this, on economic output. In addition, extreme heat

2 An example of an EWS for infectious disease is that for epidemic malaria in Botswana, where climate variability was forecast using models to provide early warning to areas that may be affected by outbreaks (Thomson et al., 2006).

reduces the ability to carry out non-work daily tasks; no research has been conducted on this issue.

Other factors that need to be taken into consideration in future research include actions to reduce heat impacts, such as workers being allowed to stop working and schools closing at predefined temperatures (often >39°C).

Impacts of temperature on food-borne disease

Heat waves may cause indirect health impacts through their effects on other systems. For example, prolonged hot weather may increase the incidence of food-borne disease outbreaks. Hot weather may also increase the prevalence of water-borne bacteria and protozoa, resulting in widespread contamination of drinking water. These issues are discussed further below.

4.1.2 Key research questions for heat research

Given the paucity of research available on heat-related mortality in Australia, it is clear that more research—involving combinations of observational and impact-assessment research—is needed in the following areas.

- Which categories of people (in city, town and countryside), in which building types and locations, are at greatest risk of death or serious illness (i.e., most 'vulnerable') to short-term extremes of heat? What kinds of heat extremes have the greatest impact on vulnerable individuals with regard to duration, magnitude and timing (day or night extremes)? What is the capacity of these individuals to acclimatise naturally to projected changes in the occurrence of heat waves? Do levels of understanding of the nature of these risks, and personal/household-level ways of ameliorating them, vary between these population subgroups?
- Are changes needed to public health policy in order to manage heat wave impacts? Answering this question will require examination of the impact of heat waves on morbidity, mortality and pre-hospital care, including:
  - differences in impacts of temperature extremes as a function of location of residence, socio-economic group, level of understanding of risks, pre-existing health status;
  - understanding the particular vulnerability of urban centres, which are often at higher risk from hot weather because of the 'urban heat island' effect (Haines et al., 2006);
  - the shape of the exposure–response graph at unusual extremes of temperature (are there important physiological coping thresholds?);
  - impacts of extremes of heat on mood, behaviour, risk exposures and work capacity;
  - combined effects of heat stress and air pollution;
  - forecasting future health risks from heat waves under climate change scenarios.
- Do EWSs for heat waves and other extreme weather events reduce adverse health impacts? Which types of EWS are most effective?
- Could existing responses to other health and social issues assist community surveillance of vulnerable individuals during heat waves?
- Does public education about the risks of extreme events, and their avoidability, alter people's knowledge and behaviour?
- Are current occupational health and safety standards in relation to climate change-induced health risks (e.g., extremes of workplace heat exposure) adequate? This would involve examination of the impacts of heat in workplaces that are not air-conditioned and the effectiveness of workplace heat monitoring and warning systems.
- What impacts would result from a change in commercial, public and private housing building codes? For example, to reduce mortality during heat waves. There is a need for simulation modelling.

Given the paucity of research available on heat-related mortality in Australia, it is clear that more research—involving combinations of observational and impact-assessment research—is needed.

4.2 Extreme weather events

4.2.1 Current knowledge and gaps

Floods, cyclones, storms and bushfires produce direct health effects and can all indirectly affect a wide range of other systems. From 1967 to 1999, deaths and injuries recorded for extreme weather events were: bushfire 223 and 4,185, cyclone 154 and 958, flood 99 and 1,019, and storms 58 and 942, respectively (BTE, 2001). The impacts of natural disasters on mental health are also significant.

The number of very high and extreme fire danger days is projected to rise by between 2% and 30% by 2020 and between 5% and 100% by 2050 (Lucas et al, 2007), while the intensity of Category 3–5 cyclones may increase by up to 60% by 2030 and up to 140% by 2070 (Abbs et al., 2006). The magnitude of these health effects will be a major focus of the Research Plan for Emergency Management.

Floods may cause an increase, after a lag period, in the prevalence of mosquitoes, other vectors of disease, and pathogens, which in turn could result in large outbreaks of disease. For example, flooding across central Queensland (Mackay, Emerald, Rockhampton) in January and February 2008 may have been the cause of a substantial increase in notifications of Ross River virus disease, due to increased standing water in the affected areas. In Queensland, there were 638 and 608 notifications in February and March 2008, respectively, compared with 143 and 392 notifications, respectively, for the same time period in 2007, when no major flooding had occurred (data from Communicable Diseases Australia: CDA, 2008).

There is a projected increase in the intensity of rainfall in Australia, but with considerable spatial variation. There is also a projected decrease in the number of tropical cyclones; however, their intensity is also projected to increase (CSIRO and BoM, 2007).

Climate change will create a substantial increase in fire weather risk in much of south-eastern Australia. As well as increasing the risks of death and injury from fire exposure, bushfires in water catchment areas can result in decreased water quality, with associated health effects.

4.2.2 Key research questions for extreme weather events

- Does public education about the risks of extreme events, and their avoidability, alter people's knowledge and behaviour?
- What is the capacity of health systems, from local to regional levels, to deal with surges in demand in response to natural disasters and to assist in longer-term recovery initiatives?[3]

4.3 Vector-borne infectious diseases, zoonoses and environmental pathogens

4.3.1 Current knowledge and gaps

Vector-borne disease

The two major changes that might be anticipated as a result of climate change are: first, changes in the incidence and distribution of infectious diseases already occurring in Australia; and, second, the introduction of infectious diseases not currently present. Ross River virus (RRV) and dengue will be used to illustrate the first issue, malaria and chikungunya the second.

RRV is the most common arbovirus disease in Australia (Russell, 1998). Considerable research efforts have gone towards elucidating the relationships between climatic variables and RRV incidence and distribution (as reviewed by Jacups et al., 2008). There is also a vast literature on vector associations and reservoir hosts (Harley et al., 2001). A number of studies have specifically addressed the prediction, using climatic variables, of RRV epidemics (Hu et al., 2004, 2006; Tong et al., 2002, 2004, 2008; Woodruff et al., 2002, 2006).

Epidemics of dengue are increasing in frequency in north Queensland, and the range is expanding worldwide (Hanna et al., 1998, 2001, 2003, 2006; Mackenzie et al., 2004). The spread of dengue in Australia is currently limited

3 It is anticipated that this will be dealt with in greater detail in the National Climate Change Adaptation Research Plan for Emergency Management.

because of restricted distribution of the dengue vector, *Aedes aegypti*; a second vector, *Ae. albopictus*, now occurs in the Torres Strait (Ritchie et al., 2006). Changes in climatic conditions in Australia are predicted to increase the range of *Ae. aegypti* (McMichael et al., 2006). The increased installation of water tanks and swimming pools, and other water-hoarding activities, may increase the breeding of mosquitoes in residential areas.

A competent malaria vector, *Anopheles farauti*, occurs in Australia, and environmental factors influencing its distribution are known (Sweeney et al., 2006). However, malaria is not endemic to Australia—cases are imported (e.g., by travellers; Liu et al., 2008) and the risk is currently managed through bio-security measures. Extrapolating from areas where malaria is endemic may prove useful in assessing the altered risks in Australia under climate change.

Chikungunya virus (CHIKV) is not yet present in Australia. It has received worldwide attention since a number of Indian Ocean epidemics between 2004 and 2006. The first non-tropical outbreak of the disease was in Italy in 2007 (Rezza et al., 2007). This has implications for Australia, as both epidemic CHIKV vectors (*Ae. aegypti* and *Ae. albopictus*) are already present in the Tropics (McMichael et al., 2006; Ritchie et al., 2006) and outbreaks can escalate rapidly in immunologically naïve populations, with person-to-person transmission via mosquitoes (i.e., without reservoir hosts; Chevillon et al., 2008).

The four mosquito-borne diseases briefly discussed above differ in the type of threat they present to Australia and the amount that is already known about the relationships between ecology, epidemiology and climate. To varying extents there are gaps in: our understanding of baseline relations between climate and infectious disease incidence; availability of good predictive models agreed to by all professional groupings involved in the area; and methodologies for the assessment of adaptive strategies for changes in the range, seasonality and incidence of infectious diseases under climate change.

Environmental pathogens and zoonoses

Two environmental pathogens, in particular, are likely to present a greater risk to health, caused by climate change. Leptospirosis is a potentially fatal disease caused by the bacterial genus *Leptospira*. These bacteria are cosmopolitan and endemic in Australia. *Leptospira* are carried by many animals, including rodents (both native and introduced), dogs, cats, domestic stock,

Under current practices in Australia, many states and territories have programs of environmental monitoring, mosquito monitoring and virus isolation, outbreak prediction, issuing of health warnings etc; and these will form a foundation for building adaptation strategies.

and many native animals (e.g., bandicoots). The bacteria are passed in the urine of the infected animal, and can be transmitted to humans when in contact with broken skin. Notifications of leptospirosis typically fluctuate around approximately 150–300 cases per year, mostly from Queensland (CDA, 2008). Rainfall can potentially increase the risk of transmission, and contamination of water supplies after heavy rain has been implicated as a source of infection.

The potentially fatal disease melioidosis has a similar mode of transmission to leptospirosis, i.e., percutaneous transmission of the bacteria *Burkholderia* spp. These bacteria survive in soils and surface water, and are endemic to northern Australia and South-east Asia (Currie, 2008). Increases in cases of melioidosis are associated with rainfall events, with fewer cases typically occurring in drier years (Inglis et al., 2004). Melioidosis has been contracted through contaminated water supplies. The transmission of both leptospirosis and melioidosis is a cross-cutting issue with water quality and surveillance.

Surveillance and early warning systems for vector-borne diseases

Under current practices in Australia, many states and territories have programs of environmental monitoring, mosquito monitoring and virus isolation, outbreak prediction, issuing of health warnings etc; and these will form a foundation for building adaptation strategies.

An important aim of elucidating how climatic conditions and processes affect infectious disease transmission is to further improve current short-term forecasting, while also creating the capacity to develop longer-term scenario-based predictive modelling. An EWS can serve as a risk management tool to enhance the ability to predict epidemics, including enabling health authorities to prepare for and act to reduce or avoid the impact of these diseases (Teklehaimanot et al., 2004a; Tong et al., 2005).

The development of spatio-temporal models has evolved rapidly in relation to the control and prevention of mosquito-borne diseases, often successfully incorporating weather and environmental data (Teklehaimanot et al., 2004a, 2004b; Thomson et al., 2006). In addition, centralised laboratory services impact on timely testing and results reporting for both surveillance and case cluster investigations. Future technologies to improve 'point of care' testing for relevant infectious diseases in predicted high-risk locations will help with the timeliness of detection and response.

May 24, 2009: Flooding in Kempsey on the NSW mid-north coast.
Image: Newspix/Nathan Edwards.

Although RRV is the most common and widespread arbovirus in Australia, little research has been done to develop an effective EWS to forecast outbreaks of RRV or other vector-borne diseases. Such EWSs may need to be modified to consider the characteristics and conditions of different socio-ecological regions of Australia, including new suburban estates. For example, new housing developments near salt marshes or other bodies of water will increase the risk of mosquito bites to the residents (Lyth et al., 2005); or flying foxes may utilise residential fruit trees or similar vegetation as an alternative source of food if weather conditions affect their usual food sources.

Similar initiatives are required for environmental pathogens, e.g., bacteria, such as those causing melioidosis and leptospirosis, and water-borne protozoa. Surveillance of vector species and changing environmental conditions needs to be strengthened.

Water scarcity has led to a recent rise in rainwater tank installations. Outbreaks of water-borne disease may occur if rainwater tanks are contaminated (e.g., by *Salmonella*). Moreover, *Ae. aegypti* has a propensity to breed in water containers around people's dwellings, and the use of rainwater tanks in combination with climatic changes may increase the susceptibility of cities such as Brisbane to dengue epidemics. A study on the surveillance of *Ae. aegypti* in rainwater tanks in northern Queensland is underway (S.A. Ritchie, personal communication, 2008). There is a need to monitor the impact of this and other responses to climate change, taking into account other determinants of receptivity to vector-borne disease (e.g., vertebrate reservoir host populations in the case of RRV, increasing human population density, etc).

Under current surveillance practices in Australia, infectious disease outbreaks are detected in retrospect, after individuals have become ill. Additional delays occur in detecting outbreaks because of the time required for laboratory testing and reporting of findings. Since this system achieves incomplete coverage, outbreaks are not detected when diagnosed cases are not reported to the health department, such as when mild symptoms are attributed to other causes (e.g., food contamination) or when treatment is not sought for individual health problems.

Although there is a National Notifiable Diseases Surveillance Scheme (NNDSS), and the Communicable Diseases Network of Australia (CDNA) coordinates interaction between jurisdictional public health units, cross-border communications and state–territory–commonwealth communications are suboptimal

December 23, 2008: Spraying for mosquito control in Cairns, Qld during a dengue fever outbreak. Image: Newspix/Jake Nowakowski.

Research should address any necessary adaptations and enhancements to the Australian communicable disease surveillance, control and prevention system in response to climate change.

for best-practice responses to outbreaks which cross jurisdictions. Australia still lacks an adequately funded equivalent of the US Centers for Disease Control (CDC). The CDNA provides publications on all notifiable infectious diseases in Australia; other institutions/ programs are also seeking to provide national notifications. The National Collaborative Research Infrastructure Strategy's (NCRIS) networked bio-security framework is about to begin, and the Northern Australian Emerging Infectious Disease Alliance (NAEIDA) is seeking support for researching diagnostics for emergent infectious diseases and for coordinating arbovirus surveillance programs.

Methodological challenges include the difficulty involved in disentangling the effects of complex epidemiology and ecology (in the case of RRV, changes in vector density, reservoir host density, and secular changes in testing methodology and patient/doctor behaviour may all be happening in parallel) from those of climate change, and the need for a 'paradigm shift' relating to the need to accept a lesser weight of proof, given the importance of climate change to human health.

4.3.2 Key research questions for vector-borne diseases

Research should address any necessary adaptations and enhancements to the Australian communicable disease surveillance, control and prevention system in response to climate change. Specific research questions include the following.

- What are the future increased risks of arbovirus diseases arising from climate change? This question should focus on population movements and changes in northern Australia, and monitoring of potential vectors.
  - Does climate-driven predictive modelling of any particular vector-borne infectious disease outbreak reduce the occurrence of such outbreaks?
  - How would existing public health systems cope with increased levels of vector-borne disease infections?
- What are the future increased risks of disease outbreaks resulting from environmental pathogens such as leptospirosis, melioidosis, and Buruli ulcer arising from the effects of extreme weather events on ground and surface water?
- What contribution can the further development of predictive models of vector distribution and outbreak risk, based on real-time and historical data from state/ territory governments, make to combating climate change impacts?
- Can improved seasonal outlooks provide useful advance warning of altered risks of vector-borne infectious disease outbreaks?
  - Does this differ between human-only and zoonotic VBDs?
  - Are such forecasts enhanced by the inclusion of information about changes in environmental indicators (e.g., surface water, vegetation levels, etc)?
  - Will the implementation of such early warning systems result in reductions in outbreaks or infection rates?
- What are the potential indirect effects of climate change (e.g., increases in household water tank numbers) on vector-borne and environment-borne diseases?
- Evaluation of vector eradication and control interventions, including economic evaluation. As an example of the very wide spectrum of research required, climate change impacts on vector-borne diseases have implications for the supply of blood. A coordinated national response is required which includes adequate surveillance systems, predictive modelling capacity, and research on the transmissibility of the disease through the blood supply. This focus is required to understand the following.
- Impact on supply capacity through either:
  - impact on donors who are directly infected;
    - the need to exclude donors who may be newly exposed to a transmissible disease on a new geographical basis;

    - impact on donors who are required to care for those infected by the disease.
- Impact on the broader health sector as a result of the modelled impact on donors.
  - How will the health sector respond to a reduced volume of blood product?

4.4 Food safety and quality

4.4.1 Current knowledge and gaps[4]

Climatic changes are expected to affect global food production. The effects are likely to be felt less critically in a wealthy country such as Australia, although higher food prices will necessarily affect the diet and nutrition of low-income groups.

Outbreaks due to food-borne pathogens are monitored by OzFoodnet across Australia. In 2005, 624 outbreaks of gastroenteritis were reported, 102 of which were food-borne (which affected over 1,900 people, including 187 hospitalisations and four deaths) (OzFoodnet Working Group, 2006). It is estimated that currently the incidence of gastroenteritis in Australia is about one case per person per year, and that about one-third of gastroenteritis is food-borne. Most infections are mild, although they can be serious in some cases, occasionally leading to death in vulnerable people. Other health outcomes can also sometimes follow certain bacterial illnesses and, while less frequent than gastroenteritis, these have potentially serious implications. These sequelae include haemolytic uraemic syndrome, Guillain Barre syndrome and rheumatoid arthritis.

The early detection of food-borne disease outbreaks currently depends on regular assessment of surveillance data that are collected for common food-borne pathogens (*Campylobacter*, *Salmonella* and others), and rapid response information from other sources that suggests a potential food-borne outbreak might be occurring. Primary prevention of outbreaks depends largely on monitoring of the food supply from paddock to plate, using a comprehensive approach to risk analysis and rapid response to problems in the food chain.

A number of infections due to food-borne pathogens are seasonal, and some studies have quantitatively estimated the effects of underlying ambient temperature and other weather variables on disease incidence. An early warning system could potentially include environmental and weather factors that are identified as risk factors for an increased likelihood of contamination in the food chain and with increased human disease outcomes. Monitoring

June 2005: Discarding spoiled perishable food during the Lismore, NSW, flood.
Image: NSW State Emergency Service.

of factors that affect the health and well-being of stock and crops, and the distribution, transport and storage of food is also relevant. Major changes in distribution and transport, such as a reduced capacity for refrigeration, may result in less than optimal food safety environments and changes in the types of food available. The most important mechanisms to prevent and control food-borne diseases are improved surveillance and monitoring, supply chain risk assessment, and improved management, communication and preparedness for potential outbreaks.

Food quality may also be affected by extreme weather events. For example, storms may cause electricity supplies to fail, resulting in food spoilage and the inability to heat food or use hot water for washing plates etc. (Cretikos et al., 2007). Heat events can also cause electricity supplies to fail (usually due to overloading of the grid), increasing the risk of food-borne diseases.

Current food distribution patterns and how they impact on disease is not well understood; the globalisation of food supplies has resulted in some international outbreaks. How food distribution patterns may be altered due to climate change, especially as the world adapts to mitigation strategies with more expensive transport, is unknown. It is possible that food supplies may once again become more localised as transport costs increase.

4.4.2 Key research questions for food safety and quality

An organisation for investigating the outbreaks and epidemiology of food-borne disease in Australia already exists: OzFoodnet conducts rigorous testing, surveillance and research on food-borne disease pathogens and outbreaks. Although research priorities for food quality exist, the activities pursued by OzFoodnet provide the basis for adaptation to emerging climate change-related food quality issues.

- Where will the likely climate change impacts on food safety and quality be observed, and what measures/practices can be implemented to reduce the risk of food-borne disease outbreaks?
- At what point in the food chain is increased vigilance most likely to reduce outbreaks of temperature-related food-borne gastroenteritis?

4.5 Air quality

4.5.1 Current knowledge and gaps

Climate change may have an impact on the concentration of air pollutants. Concentrations can rise during heat waves and may contribute to the increased mortality that occurs during prolonged hot weather (Haines et al., 2006). This has important implications for morbidity from a number of respiratory diseases, such as asthma, allergic rhinitis and chronic obstructive pulmonary disease, and mortality from these and other diseases (such as cardiovascular diseases), with their attendant social and economic costs (Galbally, 2007). Many of these conditions are already significant diseases in Australia. Asthma, for example, already affects 14–16% of children and 10–12% of adults—rates that are high by international standards (AIHW, 2005). Expenditure on asthma in Australia is also high, with the direct health expenditure alone in the 2000/2001 financial year standing at $693 million (AIHW, 2005). The impact of asthma on quality of life is also considerable.

Furthermore, longer dry periods and more frequent, more intense heat waves will result in more bushfires across Australia. Bushfires produce smoke and wind-blown dust, which has been shown to correlate with a rise in daily hospital admissions for respiratory complaints (Chen et al., 2006). Therefore, it is likely that respiratory disease-related demand on hospitals and emergency departments will broadly follow the trends given by regional climate change projections with regard to temperature, rainfall and bushfire frequency. This is significant both for seasonal and long-term preparedness planning.

These effects highlight the need for air quality monitoring and forecasting at the local, state

4 The research issues around food production and security in Australia, especially the impacts of increased drought on food cost and availability, will be addressed in the National Climate Change Adaptation Research Plan for Primary Industries.

and national levels. Climatic conditions influence the formation and dispersal (and perhaps the biological impact) of certain air pollutants. Epidemiological research and air quality monitoring are well established in Australia in relation to air pollutants as health hazards. The work of the Environment Protection Heritage Council (EPHC), at both national and state levels, is linked to a range of monitoring and evaluation bodies and processes, and these provide a rich source of information and systematic data on air quality.

The Australian Air Quality Forecasting System (AAQFS) is an example of a next-day forecasting system for air pollutants in Australia (Cope et al., 2007). Using AAQFS, the Bureau of Meteorology generates twice-daily operational forecasts for Adelaide, Melbourne and Sydney, and CSIRO generates daily forecasts of dust and smoke for the Australian continent (see http://www.csiro.au/services/AAQFS.html#Heading2).

Despite these measures, air quality and air-borne biological contaminants data in Australia are considered by some to be of a lower standard than those presented in the international literature. There is considerable scope for improvement in the monitoring of air quality and aeroallergens in Australia. In particular, there is scope to undertake targeted measurement and monitoring campaigns to better understand the processes of air pollution formation and impact under a warmer climate, such as increased emissions of biogenic reactive gases, increased particle loadings due to dust and bushfire smoke, and faster chemistry leading to more photochemical smog. It is also important to ensure that an appropriate community health message on the possible negative health consequences of poor air quality (particularly in those suffering pre-existing respiratory health problems) is communicated. In addition, an effective means of communicating information on the occurrence and forecast of poor air quality to the public is required, advising them to reduce their time spent outdoors on days affected by smog or pollen etc. Although several states already have effective systems for communicating the incidence of poor air quality, these systems could still be further improved.

4.5.2 Key research questions for air quality

- Can forecasts of impending air pollution episodes be used to minimise the health impacts due to air pollutant exposure for urban and rural communities? Both short-term forecasting and longer-term strategic modelling of air pollution have important roles to play in managing the impacts.
- What targeted measurement and monitoring is required to underpin air quality improvement programs? Which air contaminants should be measured?
- Would exploring, expanding and enhancing existing methodologies of providing information on the occurrence and forecast of poor air quality to the public be beneficial?

September 23, 2009: Dust storm in Sydney. Image: Newspix/Sam Mooy.

4.6 Water quality

4.6.1 Current knowledge and gaps

Climate change is likely to increase the intensity of heavy rainfall over most of Australia in summer (except for south-western Western Australia) and autumn (except for south-western Western Australia and south-east Queensland) and over most of northern Australia in winter and spring (CSIRO and BoM, 2007). Water quality is greatly influenced by these precipitation patterns. However, projections are associated with significant uncertainty, and we know that rainfall patterns may vary significantly at high spatial resolution; between adjoining catchments, for example (CSIRO and BoM, 2007). In a study in the USA, over 50% of water-borne disease outbreaks in the preceding 50 years were found to be significantly correlated with major precipitation events (Curriero et al., 2001). Sudden heavy rainfall, with associated flooding, can overload some sewer and storm-water systems, potentially leading to faecal contamination of storm-water released back into the environment. Heavy precipitation events will also tend to flush out pathogens from upstream water catchments, especially farm runoff, such that *Cryptosporidium*, *Giardia* and other protozoa, bacteria and viruses enter the water supply network. Research conducted in Canada demonstrated that outbreaks of enteric disease caused by *Escherichia coli*, *Campylobacter* and *Cryptosporidium* were correlated with rainfall, where heavy rain affected the surface water of catchments and dams (Thomas et al., 2006). Increases in the nutrient content and water temperature of dams, caused by heavy precipitation, can lead to blooms of cyanobacteria, which can be toxic (Hunter, 2003).

Generally speaking, Australia has given insufficient consideration to 'upstream' assessment of health risks via monitoring of water quality (with improved monitoring tools for water-borne microorganisms, especially key pathogens) as a basic adaptive strategy. The management of pathogen loads in drinking water is a priority for suppliers of mains water to cities and towns. Recent Australian research has developed a process-based mathematical model to predict levels of *E. coli*, *Cryptosporidium* and *Giardia* from drinking water catchments in New South Wales (Ferguson et al., 2007). The model used a range of variables (e.g., land use and water flow) to predict which areas of a particular catchment may be contributing the highest pathogen loads in dry, intermediate and wet weather. This model can be used to prioritise control measures for affected parts of the catchment in order to reduce the pathogen loads in drinking water (Ferguson et al., 2007). Further research would allow for better prevention and for controls that limit the impact of contamination events, especially if tied to the documentation of watershed descriptors and hydrological models providing improved modelling of water quality.

Both droughts and floods have an effect on water quality. Research on the water quality of the Rhine River on the German–Dutch border found that water quality declined in years

correlated with drought in the region, when compared with non-drought periods (Zwolsman and van Bokhoven, 2007). Reduced rainfall is also likely to increase the risk of toxic algal blooms and the salinity of drinking water (Hennessy et al., 2007).

4.6.2 Key research questions for water quality

- What water quality monitoring activities are required to support adaptation initiatives? These might include 'upstream' assessment of health risks via monitoring of water quality (with improved monitoring tools for water-borne microorganisms, particularly key pathogens of concern such as *Cryptosporidium*), especially tied to the documentation of watershed descriptors and hydrological models providing improved modelling of water quality.
- Would *combined* studies of meteorological forecasts of impending seasonal and/or extreme weather conditions, and watershed descriptors and hydrological models as tools for prioritising water quality control measures, add to adaptive capacity?
- What is the role of the existing water authorities responsible for treating water in the management of climate change impacts?

4.7 Mental health

4.7.1 Current knowledge and gaps

Climate change has the potential to lead to adverse mental health outcomes through a number of pathways. First, there is an established body of literature outlining the adverse mental health impact of natural disasters (such as floods, cyclone events, droughts and fires), and the factors that can modify the risk of poor mental health outcomes in the event of such disasters (McFarlane et al., 1997; Raphael, 1986). Any increase in the severity and frequency of natural disasters may adversely affect the mental health of communities.

Second, climate change may have an effect on a number of broad social determinants of mental health, including socio-economic adversity and effects on community viability and networks. An example is the chronic adversity of drought in many areas of Australia (Sartore et al., 2005) and the resulting heightened vulnerability to distress and mental health effects. Although the impact of drought on the mental health of rural and remote communities is difficult to assess and quantify, there is evidence that the incidence of depression is increasing. Suicide rates for agricultural workers have been consistently higher than the national average (Page and Fragar, 2002), with recent research suggesting a rate more than double the national average. Climate projections suggest that drought and prolonged dry periods will become more common in the future in much of Australia (Hennessy et al., 2008). This will affect many rural areas in particular, and economic, social and geographical problems could all contribute to an increase in the risk of mental health problems in rural communities (Berry et al., 2008; Nicholls et al., 2006).

Third, and more broadly, the threat of climate change and its consequences may have wider psychological and social effects on communities through the impact on perceptions of safety, security and fears regarding the future. The methods and tenor of communication regarding the actual or potential health and social risks associated with climate change will be important determinants of community emotional and behavioural responses. This may, in turn, be a key determinant of ways in which people respond to any demands for behaviour change or adaptation to climate change-related health risks.

Addressing these mental health factors requires methods to support community adaptation to the changes that may flow indirectly from climate change impacts, and to build preparedness for effective responses to adverse environmental events (see Appendix 1 for a typology of interventions). Resources and external supports that build social cohesion and resilience may

influence the severity and distribution of these problems. It has been observed, however, that a high degree of social cohesion is present in many rural communities (Alston, 2002; Alston and Kent, 2004; Fraser et al., 2002; Hegney et al., 2007; Judd et al., 2006; Stehlik, 2003; Stehlik et al., 1999, 2000; Wainer and Chesters, 2000), which can be beneficial in building resilience to the hardship and potential mental illness associated with changes in climate. However, little research has been undertaken into adaptive strategies to climate change-induced mental health problems, including the examination of community situations, and devising location- and community-specific adaptation strategies. In the field of family and children's health, the most substantial gaps relate to the analysis of family and children's social environments. The current worries and concerns of children are not known, and a better understanding of these may have long-term sequelae for the mental health impacts of climate-related disasters or events.[5]

Understanding the impacts of climate change on mental health as a key dimension of individual and community well-being is vital. While it is important to understand the effect of climate change-related health impacts and mental health problems on all aspects of the population, there is an increased need for an understanding of these mechanisms in rural communities, because these communities are inherently more vulnerable. This vulnerability stems from poor resourcing of the health infrastructure and services, and potentially greater exposure to adverse environmental events. Rural communities are also substantially reliant on farming and related industries, the viability of which is being compromised by climate change, leading to high stress levels in these communities.

4.7.2 Key research questions for mental health

- What interventions are required to minimise the potential harmful mental health effects of natural disasters (such as adverse climatic events), building on the established models and frameworks in disaster mental health planning? Addressing this research question will require links with climate scientists and modellers to explore how future climatic variability and extreme weather events will affect population mental health.
- What interventions at a broad community level are most effective in reducing the adverse mental health impacts of climate/environmental changes in rural Australia? Addressing this research question will require determination of the relationship between changes in climate and mental health, especially common mental health problems, in rural individuals, households and communities:
  - identification of at-risk groups;
  - determinants of community and family resilience and coping capacities;
  - impact of climate change on known social determinants of mental health;
  - responses to the perceived impact on future hopes and expectations.
- Is stress and anxiety about 'global warming' in children and adults affecting their quality of life? What types of information, education and discussion are most effective in addressing concerns and galvanising positive coping responses to climate change—and, for each, in what age-ranges? Do such interventions also lead to changes in child and family behaviours? This will require research into how children and young people respond to the risks posed by climate change, including perceptions, anxieties of children and young people, and parent-transmitted stresses.
- What disease categories within 'mental health' are likely to be vulnerable to climate change impacts? For example, considering the categories of psychiatric disorders typical during old age, how would different aspects of adverse climate change affect these?
- How is mental health likely to be affected by socio-economic factors related to impacts of climate change, including:
  - financial strain and insecurity, including loss (actual, threatened) of livelihoods;

5 See also *Children's Environmental Health Issues in Australia: Australian Research Alliance for Children and Youth Report*, April 2008.

  - emotional responses to the degradation of the land and suffering of wild and domesticated animals;
  - hopelessness (and its associations with distress) in the face of uncontrollable adverse events;
  - increasing social and economic inequality (between and within communities)?
- What methods of community-wide education and information will support effective adaptation and minimise distress?

4.8 Community and Indigenous health

4.8.1 Current knowledge and gaps

When considering climate change impacts on human health, it is important to acknowledge the great diversity of communities—from urban centres to the most remote settlements—and to ensure that, to the greatest extent possible, research is able to accommodate the unique characteristics of each. In this regard, it will be essential to involve communities in determining appropriate research questions, in undertaking research, and in interpreting and disseminating research findings. This will be particularly important in vulnerable communities and among vulnerable Australians, particularly Indigenous Australians and people from linguistically and culturally diverse backgrounds.

Indigenous Australians living in remote communities in the northern and central regions of the country are likely to be disproportionately disadvantaged by the adverse impacts of climate change. Their vulnerability is heightened due to at least three factors: (i) existing non-climate stresses; (ii) a culture that does not necessarily differentiate between natural and human systems in relation to the concept of 'health' (Green, 2006a); and (iii) a connection between the need to ensure the well-being of country, 'caring for country', and health (H. Berry, personal communication, 2008). The first factor reduces a community's resilience to a changing environment. The second suggests that biophysical changes affecting the 'health' of an ecosystem are likely also to impact individuals' physical and mental well-being, as well as the 'health' of a community's cultural cohesion. The third factor is important because an inability to 'keep country healthy' or the loss of culturally significant country (particularly coastal land) due to climate change and sea level rise, would be likely to have a differentially profound effect on Indigenous Australians. This interconnection between Indigenous Australians'

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'country' and community well-being means that assessments of how climate change is likely to affect Indigenous people's health must also factor in climate impacts on the land and marine ecosystems of their country.

There is a limited literature on the health impacts caused by climate change for the Australian population. The report, *Climate Change Health Impacts in Australia*, does identify the impact of various greenhouse gas emission mitigation strategies on health, but does not specifically assess the impacts for Indigenous populations (Woodruff et al., 2005). Of more relevance to Indigenous Australian communities, Currie (2001) highlights the potential impacts of climate change in northern Australia, specifically focusing on infectious disease patterns. Concerns have been raised that climate change could allow new diseases, such as avian influenza, to enter Australia from the north, and new pests, such as screw worm fly, to infest feral animals, but these concerns have not yet been quantitatively assessed or documented (J. Morrison, personal communication, 2008). Green (2006b) provides the most up-to-date compilation of likely health impacts for Indigenous Australians. Adaptive capacity to a changing climate may be reduced for many Indigenous communities, due to a range of factors including poor infrastructure, low economic status, and existing chronic health problems.

Community engagement is an integral part of wider (local and national scale) climate change adaptation (Ebi and Semenza, 2008). The central issue for communities is vulnerability. How communities can cope with the health impacts attributed to climate change needs to be evaluated, to ensure that they have the tools, knowledge and facilities to adjust to life in a changing climate. This is particularly important for rural areas, where facilities may not be of the same standard as those in cities. There are many cross-cutting issues associated with evaluating community vulnerability. These include the role of individuals, building community cohesion, and equity issues.

4.8.2 Key research questions for community and Indigenous health

- Which types of intervention most effectively increase the level of community resilience?
  - What key characteristics of Indigenous, rural and urban communities determine their level of resilience to the stress of long-term changes in climatic and environmental conditions? This will involve research into community

The Royal Flying Doctor Service assisting rural and remote communties. Image: RFDS.

engagement, including controlled intervention studies, to examine what works in a community approach.

- How might climate change and climatic extremes affect aspects of Indigenous culture and living conditions that affect health, including:
  - residential and working conditions (in relation to heat extremes);
  - supplies of fresh water;
  - distribution and supplies of traditional food sources;
  - potential conflict situations if/when some vulnerable (e.g., low-lying coastal) communities are relocated;
  - increased exposure, in some locations, to extreme weather events?
- Research in this area requires an understanding of the vulnerability of groups and communities, and key drivers of health such as socio-economic status. It also requires engagement and communication with the most vulnerable groups, preferably through a participatory action approach that works closely with relevant communities. In addition, the development of systematic approaches to identifying, evaluating and implementing adaptive strategies to lessen the health risks of climate change, especially in vulnerable groups, needs to be undertaken. There is a need to build research capacity in this area including:
  - evaluation of programs to assist communities to adapt to climate change impacts;
  - using scientific evaluations of policy initiatives, programs and interventions to enable academic researchers and policy-makers to work together;
  - developing long-term research targets, and building the research base and the capacity required to achieve these targets;
  - building strong collaborations with key rural stakeholders, with all levels of government, and with the non-profit service-delivery sector.
- Will climate change increase intergenerational health and social inequities, and for whom? How might policy and intervention reduce intergenerational inequities linked to climate change?

4.9 Health care services and infrastructure

4.9.1 Current knowledge and gaps

There is a strong need for adequate hospital and primary care systems to cope with a potential increase in climate change-related illness. There is also a range of monitoring and analysis work required to ensure that the health system is designed in the best way to support individual, community and institutional adaptation. The key research questions listed in the following section should include the specific consideration of groups with high levels of dependence on the health sector, including the aged and chronically sick, and all those who are cared for in the community. This consideration should extend to the adequacy of design, construction and operation of residential facilities, for example for care of the aged.

4.9.2 Key research questions for health care services and infrastructure

- Is the health care system adequately structured, staffed and resourced to handle increased demands from (i) extreme weather events and (ii) outbreaks of infectious diseases? What improvements are needed, feasible and effective? What are the additional workforce requirements for professions such as environmental health and epidemiology, which will be important in surveillance and in primary and secondary prevention? Is health infrastructure planned for less-vulnerable locations? What models of integrating the entire health sector's adaptive responses best support the coordination of adaptive activities?
- What models of linkage and knowledge exchange between climate change researchers and policy-makers best provide relevant decision support in planning health sector responses?
- What role should the primary health care sector play as part of a broader public health adaptive response to climate change?
- What forms of in-career training of health care and related professionals best prepare them to identify and respond to climate-related health impacts?
- How do the strategies for the mitigation of greenhouse gas emissions interact with the strategies to adapt to the health impacts of climate change, and how might these interactions be managed?

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5. Prioritising climate change-related health research

5.1 Criteria and considerations for prioritising research activities

Actions aimed at addressing the impacts of climate change span a wide spectrum of sectors. The COAG National Climate Change Adaptation Framework 2007 identifies eight sectoral areas, including human health, for implementing adaptation actions. Since the resources and capacity currently available in Australia for adaptation research are limited, the National Climate Change Adaptation Research Facility has developed a set of five criteria to be used for prioritising research topics within each theme area (see Appendix 3 for details). These criteria are being used in the context of all the Research Plans being developed by the Facility.

In relation to this Research Plan on Human Health, a sixth criterion, related to equity issues, has been added. The criteria are:

1. Severity of potential impact/degree of potential benefit.
2. Immediacy of required intervention/response.
3. Need to change current intervention/ practicality of intervention.
4. Potential for co-benefits (desirable).
5. Cross-sectoral relevance (desirable).
6. Distribution and equity considerations surrounding the perceived beneficiaries of the research and resulting adaptation strategies.

A number of issues need to be considered when assessing priorities for climate change and health research, in order to achieve the 'best' outcomes. An essential front-end need is for information about the (likely) magnitude of adverse health impacts due to climate change, in order to guide decisions about the choice of adaptive interventions.

The relationship(s) between background (i.e., natural) climate variations and the

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specified health outcome(s) must be sufficiently well understood, and the burden of disease attributable to such variations can then be estimated. This provides an indication of the likely impact of climate change on that/those health outcome(s).

It is relevant to seek evidence of actual health impacts of climate change, particularly in vulnerable regions or communities, although other factors will affect the amount of evidence required to guide decision-making. For example, less evidence may be needed to justify the implementation of a heat wave early warning system, since it will be a relatively low-cost undertaking and will be useful in both current and future situations in any event. Adaptive strategies for other health problems (e.g., some infectious diseases) may require a larger base of evidence to demonstrate the risk to health before they are deemed justifiable.

Scenario-based modelling can be used to forecast the health risks posed by future plausible changes in climate. Adaptive strategies will often need to have a significant anticipatory dimension to them.

Research into adaptation and adaptive strategies must address both short- and long-term time horizons. For example, in relation to the health risks from heat waves we could improve our early warning systems immediately, in order to achieve immediate reductions in excess mortality. In the long term, however, there will also be a need to render both urban environment and housing design less heat-trapping, drawing on the skills of urban planners, architects and developers.

A crucial task is to determine who is at the greatest risk of adverse health effects of climate change. Groups and communities that may be at elevated risk include rural communities, Indigenous communities, and the very young and the elderly. In general, adaptive strategies should pay particular attention to the needs of these subgroups. Researchers will therefore often need to engage and communicate with vulnerable groups to determine how they will be affected and how they will cope with the health risks or the actual impacts. Appendix 2 shows a recent tabulation of vulnerable groups in the USA, prepared by the Centers for Disease Control.

Left: First aid during the Gippsland, Vic, 2006 bushfires. Image: Australian Red Cross/ Shannon Reddaway. **Right: June 2007 floods in Wyong, NSW.** Image: NSW State Emergency Service.

5.2 Prioritising research activities related to human health and climate change

Ranking areas for research into high and low priority is difficult, given that many aspects of research are not directly comparable and time-frames for research vary. Nonetheless, an attempt is made to apply the six prioritisation criteria to the summary list of key research questions identified under each of the nine sub-themes in Section 4.

Applying these criteria, research priorities were ranked from low to high. The full assessment matrix is in Appendix 4. From this, the following list of priority topics emerged (Table 2), with a higher need identified in relation to heat waves, vector-borne disease, and health infrastructure and services.

Cooling off in the January 2009 Victorian heatwave. Image: Newspix/Rob Leeson.

Table 2. Priority research questions

Heat

- Which categories of people, in city, town and countryside, are at greatest risk of death or serious illness (i.e., most 'vulnerable') from short-term extremes of heat? Do levels of understanding of the nature of these risks, and personal/household-level ways of ameliorating them, vary between these population subgroups? Are there changes that are needed for mainstream policy for public health?
- Do early warning systems for heat waves and other extreme weather events reduce adverse health impacts? Which types work best?

Extreme weather events

- Does public education about the risks of extreme events, and their avoidability, alter people's knowledge and behaviour?

Vector-borne disease

- What are the future risks associated with arbovirus diseases, with a particular focus on population movements and changes in northern Australia, and monitoring of potential vectors? Does climate-driven predictive modelling of any particular vector-borne infectious disease outbreak reduce its occurrence?
- Can meteorological forecasts of impending seasonal weather conditions provide useful advance warning of altered risks of vector-borne infectious disease outbreaks? Does this differ between human-only and zoonotic VBDs? Are such forecasts enhanced by inclusion of information about changes in environmental indicators (e.g., surface water, vegetation levels, etc)? Will the implementation of such early warning systems result in reductions in outbreaks or infection rates?

Food, air and water quality

- Where will the likely climate change impacts on food safety and quality be observed, and what measures/practices can be implemented to reduce the risk of food-borne disease outbreaks?
- What is the role of water authorities responsible for treating water in the management of climate change impacts?

Mental health

- What interventions are required to minimise the potential harmful mental health effects of natural disasters (such as drought and adverse climatic events), building on the established models and frameworks in disaster mental health planning?

Community and Indigenous health

- Which types of intervention most effectively increase the level of community resilience? What key characteristics of rural and urban communities determine their level of resilience to the stress of long-term changes in climatic and environmental conditions?
- How might climate change and climatic extremes affect aspects of Indigenous culture and living conditions that affect health?

Health care system and infrastructure issues

- What models of integrating the entire health sector's adaptive responses best support coordination of adaptive activities?
- What models of linkage and knowledge exchange between climate change researchers and policy-makers best provide relevant decision support in planning health sector responses?
- What role should the primary health care sector play as part of a broader public health adaptive response to climate change?
- Is the health care system adequately structured and staffed to handle increased demands from (i) extreme weather events and (ii) outbreaks of infectious diseases? What improvements are needed, feasible and effective?
- What forms of in-career training of health care professionals best prepare them to identify and respond to climate-related health impacts?

6. Cross-cutting, methodological and implementation issues

The area of health research in the context of climate change is complex, encompassing a range of research disciplines, sectors and stakeholders. The methods used to conduct research will often require wide consultation and broad collaboration. The two fields of climate change science and health impacts research include many highly qualified individuals with expertise in essential disciplines that will mutually benefit from linkages, networks and formal collaboration. It will be important to establish which research methods will best capture different types of data from various areas (e.g., urban vs. rural areas).

6.1 Evaluation research

The interface between researchers and policy-makers is critical if effective and enduring policy decisions are to be made and strategies and programs established. Therefore, the evaluation of interventions needs to be seen as an opportunity to engage stakeholders, researchers and government in novel, challenging, outcome-oriented and diverse ways, with a view to developing and refining policy that is both appropriate and well-received.

In order to plan an appropriate adaptation strategy, it is important to learn what communities understand about climate change risk. It is also important to understand what communities think climate adaptation is, and what they are willing to do or to tolerate in order to achieve it. A formal evaluation can be used to elucidate community awareness of risk. Similarly, a formal evaluation can be used to identify how skills and experts can be pooled to maximise knowledge and research resources for these topics.

There is currently a lack of skills in Australia in relation to process evaluation and in the evaluation of community-led activities. It will be necessary to ensure that particular (types of) evaluations are given appropriate funding and personnel commensurate with the importance and individual needs of each project. For example, it will be necessary to know the current evaluation capacity of the health and social policy sectors and to address inadequacies in capacity.

Evaluation can also be used to bring together policy and research experts in a structured manner, to work on specific shared projects in which both have an important stake. It is essential that careful planning and consulting be conducted before evaluations take place; all appropriate stakeholders must be included, especially in community evaluations, while taking care not to over-consult. Time-frames must be given special attention, as evaluations can take a long time to complete.

6.2 Understanding the relative roles of observational and experimental studies

Observational studies will be widely applicable in the evaluation of adaptive strategies. For example, the relative effectiveness of heat wave warning systems in various states can be compared. There will be confounding variables (non-climate differences between states), however, that need to be taken into account, such as levels of prior knowledge, public education, and acclimatisation.

The role of formal experimental studies in climate change adaptation research is limited, in particular because of the long-term nature of many adaptive strategies. Traditional empirical testing of hypotheses in relation to long-term adaptive strategies is simply not feasible, as this would require years of monitoring to obtain significant results, which then would be passed on to policy-makers. This method of research would not allow the early implementation of adaptive strategies (Haines et al., 2006). In these instances, mathematical modelling of changes in future health risks will need to be used to provide an estimate of the results of a particular strategy, thereby enabling it to be implemented without delay.

6.3 Prioritising and choice of data collection

Before embarking on new data collections, it is necessary to find and examine the existing data and evaluate its quality. Describing and evaluating the quality and quantity of existing data will highlight any inadequacies or gaps, which will then be used to assist in the design of new data collections. Heterogeneity in the quality and quantity of data collected independently (e.g., by states, councils) may result in datasets that are incompatible, making a comparison of findings across different jurisdictions difficult. One way to alleviate this is to introduce or adopt national standards for data collection, although any serendipitous data-mining or comparisons from different areas may be lost as a result.

It is essential that the research priorities for climate change and health, particularly relating to vulnerability and evaluation of adaptive strategies, are identified first, so as to ensure that the most appropriate and useful data are being collected. Expert stakeholders and other NARPs can be utilised to determine the scale, consistency and analysis for new data collections, to ensure that they will be consistent with the requirements of clearly identified research priorities. One way to improve access and quality of data is to establish a national database, to be made available to appropriately qualified researchers.

6.4 Standardising methodologies

There is a need to standardise the methodology used for geographical mapping of vector-borne diseases. An example is the work on RRV outbreaks. Gatton et al. (2005) used a specific definition for such outbreaks, whereas Tong et al. (2001) used localities (suburbs or townships) as their unit of study in work examining the spatio-temporal distribution of RRV transmission. Although these two studies addressed different research questions, efforts to standardise measures of disease frequency, accessed from a uniform dataset, may enable a better understanding and quantification of the impact of climate change on vector-borne diseases and their vectors. Results from current research can be used to show which data are the most important to collect. Uniform national methodologies are needed to measure responses of vector abundance and disease frequency in relation to climate change.

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6.5 Time-frames for priority research

The amount of time needed to conduct, analyse and disseminate the results of the priority research will vary greatly. There is, however, a trade-off between time taken and effective use of results. While a longer study into the health effects of heat will provide comprehensive results to be implemented into policy, a shorter study can influence changes to policy faster, which may save more lives immediately rather than in 5 years' time.

The lag between the time taken for research and the implementation of results and recommendations can be reduced somewhat by the use of predictive modelling, where applicable. For example, research to discover whether changes in building codes have a positive effect on public health will take years of monitoring in order to generate significant results. Instead, a shorter project based on simulations and modelling of the potential outcomes of certain building designs will facilitate the rapid implementation of changes to building codes in order to protect community health. Generally, most climate change-related health impacts research would be completed over a time period of 1–5 years.

6.6 Analyses of future climate change

There are a number of current and readily accessible products and projects which, while not designed specifically for health-specific research, can still be useful. For example, future climate projections will be improved via the Bureau of Meteorology/CSIRO-funded Australian Community Climate and Earth-System Simulator (ACCESS),[6] as well as a proposed Climate Projections Online database of long-term model outlooks both from Australia and from modelling institutes around the world.

The modelling of future climate change scenarios is a dynamic evolving exercise. Over the coming several years, there will be further gains (in Australia) in downscaling, and in forecasting region- and perhaps location-specific changes in climate and climate variability. There may also be some modulation of the range of scenarios as climate modelling is updated with the latest observed trends.

October 1993: Floods in North Eastern Victoria. Image: Sandi Mason.

6 See http://www.accessimulator.org.au/.

7. Indicative budget for priority research

7.1 Budget considerations

The costs of research vary greatly between sectors. There are, however, some costs (relating to personnel, equipment and administration of projects, and auspicing) that are common across all sectors. The costs of climate change health research will depend on a number of factors, as discussed below, and will vary very substantially according to the characteristics of the research with respect to these factors.

Research scale, duration, content

The costs of 'research' can vary significantly from one small study or project, conducted over a period of a few months with straightforward content and minimal personnel, to large multi-study integrated research programs conducted by large, top-heavy research teams in highly complex topic areas over a number of years. An indicative cost range for the former will be from $30,000 to $70,000. At the conservative end of the latter, a range of $5 to $10 million over a 5-year period might be expected, which would support a small team undertaking complex but relatively inexpensive research (excluding data collection).

While shorter-term projects may cost less up-front, they are unable to deliver the long-term results required for particular cases. Proposals that cover longer time periods may, in spite of being more expensive, provide better and more enduring results. For example, a 12-month study on the health effects of heat events on the elderly would cost approximately $50,000 to $100,000; whereas a 36-month follow-up study on a similar topic, collecting more data at a local and household level, has been estimated to cost $650,000. The longer study with a richer dataset would provide better information and understanding, including data on some important factors that may guide the choice and calibration of intervention strategies. Similarly, an observation-based comparative assessment of the statistical impact of between three and five different (state-based or city-based) early warning systems on excess death rates during heat waves might cost $100,000. An evaluation of the impact of changes in urban and suburban layout (open space, green space, wind corridors) on the 'urban heat island' phenomenon and the associated risks to health from extremes of heat exposure would be more expensive and demanding of both on-ground data collection and spatio-temporal modelling of relevant phenomena. The latter study would provide a stronger basis for achieving sustainable urban living patterns and enduring protection of human health. The former would require recurrent annual expenditure for an activity which, if taken in isolation of other adaptation actions, would be essentially 'defensive'.

Data type and source

The costs of collecting qualitative and quantitative data will vary considerably depending on study design and sample size, with economies of scale often operating in larger studies. The collection of qualitative data tends to vary primarily with the number of participants (e.g., the number of interviews, focus groups or natural setting observations conducted) and the length of observation (e.g., the length of interviews). This is because there is a one-to-one relationship between the extent of data collection and researcher time (for example, in conducting, transcribing and coding interviews).

The cheapest form of data collection uses anonymous questionnaire-based cross-sectional data from a convenience sample, while large multilevel panel studies are the most expensive. Other possibilities include large random-sample cross-sectional studies conducted at one or multiple time points, and smaller studies nested within larger studies, which benefit financially from the infrastructure investment in the larger study. Accessing data from children or from vulnerable or other hard-to-reach subpopulations adds further to costs. Alternatives to collecting new data include re-analysing existing research datasets with new research questions, data-mining, and accessing other kinds of data, such as Medicare or pharmaceutical use data, census data and climate data. Data collected from multiple sources will typically be matched or merged, which is a difficult and expensive process. Further costs are often incurred in the process of accessing the data, such as navigating bureaucratic processes and managing ethics applications.

Type of study

The simplest type of study would include undertaking literature reviews or other desk-based information gathering. An indicative cost range for a simple study (literature review or desktop research) would be from $20,000 for a very brief and simple literature review to $150,000 for a complex review of a large topic. Systematic reviews of the literature, particularly where they may include meta-analysis, and studies involving data collection and/or merging and data analysis, are more expensive. A single study of this kind, such as might be reported in a single journal article or report, involving one researcher with part-time research assistance and no data collection, could cost from around $60,000.

Participative approach

Climate change-related health research will require a greater use of participative research approaches than has been usual in academic research in the past. Research partners will include academic researchers, government representatives, non-profit organisations, the business sector, and other groups. Access can be a complicated matter, with challenges in multiple domains including problems of physical access (e.g., whether partners are in metropolitan centres or remote locations), permission (e.g., in accessing Indigenous partners), administrative difficulties (e.g., in accessing prison populations), other moral or ethical considerations, and partner costs (e.g., remuneration for participants' time or travel, accommodation, out-of-pocket and other expenses).

7.2 Potential collaborators and additional funding resources

Some of the funding for the research priorities identified in this Plan will be available through Commonwealth funding programs, including those from the Department of Climate Change, the National Health and Medical Research Council (NHMRC) and the Australian Research Council (ARC). The CSIRO Climate Adaptation Flagship is an additional potential source of research funding.

Additional funding for climate change-related health research may come from state/territory and local governments, the private sector, and others, including charities and philanthropies. With respect to the prospects for support from, and collaboration with, the private sector, there is increasing interest in the general topic of impacts and risks from climate change, in particular from the urban development and infrastructure sector and from the insurance industry—both property and health insurance.

Climate change-related health research will require a greater use of participative research approaches than has been usual in academic research in the past. Research partners will include academic researchers, government representatives, non-profit organisations, the business sector, and other groups.

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January 29, 2009: Williamstown Beach, Melbourne. Image: Newspix/Darryl Gregory.

Appendix 1

Example of typology of interventions for mental health impacts of climate change (adapted from Berry et al., 2008)

1. Proactive primary prevention (Universal)

Preventing exposure to climate change risks

Intervention level (Micro to Macro)			
Individual	**Household**	**Community**	**Region**
General education, training and personal development, social skills, individual community participation.	General household strengthening and skills development using existing services and frameworks; increase participation in community; Focus on life-span perspective (e.g., children, youth, parents, older people).	Social capital building; cultivating initiatives determined by local communities; broad-based education and community competencies training to achieve community-driven goals (e.g., economic, water or food security); resilience-building for whole or parts of community.	Regional economic and social development; encouragement of new businesses, industries, technologies; enhanced general education and skills training; links to other policy areas; acceptance and valuing of cultural diversity; identify potential impacts on ATSI people; role of media and local government in promoting adaptation to change. Planning how to use media for public awareness. Managing stakeholder relationships.

2. Reactive primary prevention (Selective)

Preventing health problems from developing as a result of exposure

Intervention level (Micro to Macro)			
Individual	**Household**	**Community**	**Region**
Education, training and personal development (e.g., in schools, adult educational or workplace settings); vulnerable people targeted.	Specific household-based education and skills development using existing services where possible; vulnerable households targeted.	Engagement of broad range of health and human services sectors in mental health promotion programs. Build community leadership in these programs. Coordinate health and social services; identify service gaps; train service providers. Vulnerable communities targeted.	Policy and program design, develop information kits, enhance or maintain health and social service infrastructure; fund or advocate for new services. Link in with state and federal governments. Coordination of emergency services sector, rural assistance agencies. Use of media for public awareness. Vulnerable regions targeted.

3. Secondary prevention (Indicated)

Early intervention to treat symptoms in early stage

Intervention level (Micro to Macro)			
Individual	**Household**	**Community**	**Region**
Targeted individual crisis intervention or support, for practical needs, counselling.	Targeted household crisis intervention or support, for practical needs, counselling. Build community confidence in health and human services.	Engagement of gate-keeper or front-line agencies in improved pathways to assistance; build capacity for intersectoral collaboration in improving access to services; engagement with primary care (GP sector).	Increase availability of effective, low-cost, easy to deliver interventions when needed; increase capacity of generalist health and human service sector to provide basic health care when needed across all age groups and build greater links across primary and secondary service sectors. E-health initiatives.

4. Tertiary prevention

Managing long-term prevention/adaptation strategies and management of long-term health effects

Intervention level (Micro to Macro)			
Individual	**Household**	**Community**	**Region**
Professional or medical assistance, long-term case management.	Professional or medical assistance for households with member/s with ongoing problem (e.g., mental health problem), respite options for carers, long-term household-based case management.	Community-level implementation of adaptation and mitigation programs.	Regional services—full spectrum of health services to include recovery programs with enhanced community based services; options for extremely remote locations (e.g., video-conferencing; telepsychiatry). Use of media for public awareness.

Appendix 2

Anticipated health effects of climate change in the United States (from Frumkin et al., 2008)

Weather Event	Health Effects	Populations Most Affected	Additional US Health Burden
Heat waves	Heat stress	The very old; athletes; the socially isolated; the poor; those with respiratory disease	Low to moderate
Extreme weather events	Injuries; drowning	Coastal, low-lying land dwellers; the poor	Uncertain; likely moderate
Winter weather anomalies (e.g., rain, ice)	Slips and falls; motor vehicle crashes	Dwellers in northern climates; elderly people; drivers	
Sea-level rise	Injuries; drowning; water and soil salinization, ecosystem and economic disruption	Coastal dwellers; those with low socio-economic status (SES[7])	Low
Increased ozone and pollen formation	Respiratory disease exacerbation (e.g., COPD[8], asthma, allergic rhinitis, bronchitis)	The elderly; children; those with respiratory disease	Low to moderate
Drought, ecosystem migration	Food and water shortages; malnutrition	Those with low socio-economic status; elderly; children	Low
Droughts, floods, increased mean temperature	Food and water-borne diseases	Swimmers; multiple populations at risk depending on outcome of interest	Low to moderate
Droughts, floods, increased mean temperature	Vector-borne disease	Outdoor workers; people pursuing outdoor recreation; the poor (without air conditioning/ window screens)	Low to moderate
Extreme weather events; drought	Mass population movement; international conflict	General population	Uncertain; potentially moderate to high
Climate change generally; extreme events	Mental health	The young; the displaced; those with depression or anxiety	Uncertain; potentially moderate

7 Socio-Economic Status
8 Chronic Obstructive Pulmonary Disease
9 Emergency Department
10 Federal Emergency Management Agency

Nonclimate Determinants	Adaptation Measures	Health Data Sources for Surveillance	Meteorological and Other Data for Surveillance
Acclimation; built environment	Architecture; air conditioning; warning systems; distributed, resilient, "smart power grid"; community response	ED[9] and ambulatory visits; hospital admissions; mortality	Daily minimum and maximum temperatures; humidity; soil moisture
Engineering; zoning and land-use policies	Architecture; engineering; planning; early warning systems	Attributed risk; ED visits; hospital admissions; FEMA[10] records; mortality	Meteorological event data; extent, timing, severity; return time for rare events
	Public education; mass transit	ED visits	Meteorological event data
Water pollution; storms; coastal development; land-use policies	Sea walls and levees; abandonment	Attributed risk; ED and ambulatory visits; mental health measures (indirect effects)	Satellite mapping of coastal areas; sea level and tidal surge records
Smoking; air quality; respiratory infections; industrial activity; electric demand and production mode; access to health care	Pollution controls; air conditioning; education; medical therapy	ED and ambulatory visits; hospital admissions	Daily and weekly temperature; rainfall; pollen counts; ozone levels; particulate measures
Population growth; food distribution systems; economic and trade issues; biotechnology; petroleum cost	Technological advances; enhanced delivery systems; trade negotiations	Growth monitoring; food insecurity data	Crop yields; rainfall patterns; data on food sources and marketing
Travel; land use; water treatment and quality; housing quality; food-handling practices	Public education; water treatment; medical treatment; watershed management	Disease surveillance; ED and ambulatory visits; seasonal patterns in incidence; focused observations at geographic margins	Temperature and rainfall data; vector population and habitat/range monitoring
Travel; vector and animal host distribution; habitat change; land use	Public education; vector control; medical prophylaxis and treatment; vaccination	Disease surveillance; ED and ambulatory visits; focused observations at geographic margins	Temperature and rainfall data; vector population and habitat/range monitoring
Sociopolitical factors; resource use and conflicts; economic development	Negotiation and conflict mediation; postdisaster response	Event and population movement monitoring; mental health outcomes surveillance	Meteorological event data; regional economic and resource use data
Baseline mental health disease burden	Health communication; postdisaster mental health outreach; various therapeutic and medical management options	Mental health outcomes surveillance	Correlation of mental health outcomes with regional variable responses to extreme events; climate change as a whole

Appendix 3

Criteria for setting research priorities

The Department of Climate Change and the National Climate Change Adaptation Research Facility are developing a series of National Climate Change Adaptation Research Plans for identified priority theme areas. The research plans will identify critical gaps in the information needed by sectoral decision-makers, set research priorities based on these gaps, and identify capacity that could be harnessed to conduct priority research.

The criteria listed below will guide the research planning process to set research priorities in the priority theme areas.

1. Severity of potential impact or degree of potential benefit

What is the severity of the potential impact to be addressed or benefit to be gained by the research? Potentially irreversible impacts and those that have a greater severity (in social, economic or environmental terms) will be awarded higher priority.

2. Immediacy of required intervention or response

Research will be prioritised according to the timeliness of the response needed. How immediate is the intervention or response needed to address the potential impact or create the benefit? Research that must begin now in order to inform timely responses will receive a higher priority than research that could be conducted at a later date and still enable a timely response.

3. Need to change intervention or practicality of intervention

Is there a need to change the intervention used currently to address the potential impact being considered? If yes, what are the alternatives and how practical are these alternative interventions? Research that will contribute to practicable interventions or responses will be prioritised. Does research into the potential impact of the intervention being considered contribute to the knowledge base required to support decisions about these interventions?

Desirable

4. Potential for co-benefits

Will the research being considered produce any benefits beyond informing climate adaptation strategies?

5. Potential to address multiple, including cross-sectoral, issues

Will the research being considered address more than one issue, including cross-sectoral issues?

6. Distribution and equity considerations

Who will benefit from any adaptation strategy?

Appendix 4

National Climate Change Adaptation Research Plan for Human Health: setting research priorities

Sub-theme/ Research activity	Severity/Benefit	Immediacy	Need to change intervention/ Practicality
Heat			
Understanding heat risks, based on location, health status, age and other factors	Impact: High and well understood Potential for thousands of additional deaths	High Expected impacts now and in future	Good reasons to believe interventions will be practicable
Early warning systems, including applicability or adaptability of other forms of community surveillance of vulnerable individuals	Benefit: Medium-high Correlation between heat and increased morbidity/ mortality—capable of being addressed through effective strategies	Medium-high Heat waves already occur, so benefit could be immediate	Intervention practical —evidence that EWS can trigger effective public health strategies
OH&S[11] standards	Benefit: Medium-high	Medium-high	Changes may be required to some interventions; interventions will be practicable
Building codes	Benefit: Medium-high	Medium-high	Changes may be required to some interventions; interventions will be practicable
Extreme weather events			
Effectiveness of public education	Impact: High Potential for increased incidence of extreme events in vulnerable areas; potential for 2+ events to occur close together	High Expected impacts in vulnerable areas in the near-term future	Changes to some interventions may be needed; interventions will probably be practicable
Vector-borne diseases			
Predictive modelling of future risks of particular VBD[12] outbreaks	Benefit: Medium-low Potential for increased incidence of VBD outbreaks in vulnerable areas	Medium-low Expected impacts in vulnerable regions in future	No urgency to change current interventions, but may require introduction of existing interventions in new places Practicability of changed interventions to be assessed
EWS and meteorological forecasting of weather conditions	Benefit: Medium-low	Medium-low	No urgency to change current interventions, but developing EWS may make future interventions more efficient/targeted Changed interventions need to be identified and practicability assessed

11 Occupational Health and Safety
12 Vector-Borne Disease

Potential co-benefits	Cross-sectoral relevance	Distributional justice/ Equity issues	Conclusions
Beneficial for addressing existing problems with heat stress	Relevance to the Settlements and Infrastructure theme in building design and urban planning	Some groups more vulnerable, e.g., the elderly, sufferers from other health conditions	**Medium–high priority** Well understood but further information required in critical areas
Benefits in other areas as well (e.g., early warning for potential impacts on food/ water quality)		Some groups more vulnerable, e.g., the elderly, sufferers from other health conditions Relevant to design of effective system	**High priority** Research needed on details of effectiveness and design of the EWS
Benefits in OH&S domains		Outdoor workers and workers in poorly ventilated/cooled environments likely to be more seriously affected	**Medium priority** Some research needed on adequacy of existing OH&S standards
Benefits in energy efficiency domain	Relevance to the Settlements and Infrastructure theme in building design and urban planning		**Medium priority** Research required re building codes
Benefits in addressing existing problems related to post-event response and recovery, and water quality	Relevance to the Settlements and Infrastructure, and Emergency Management themes Broader relevance to other issues requiring public awareness and education	Some groups will be more vulnerable to extreme events —effectiveness of awareness for them important	**Medium–high priority** Research into whether public education on risks alters people's knowledge and behaviour
Beneficial in addressing existing problems in vulnerable areas	Relevance to the Settlements and Infrastructure theme redesign and planning of built environment	Likely to affect regions already vulnerable to other climate change impacts	**High priority** Research required into potential contribution of predictive models to VBD prevention strategies, especially in northern Australia
			Medium priority Some research required into whether forecasting provides useful warning and contributes to prevention strategies

Sub-theme/ Research activity	Severity/Benefit	Immediacy	Need to change intervention/ Practicality
Food quality			
Incidence of food-borne risk along the food chain	Impact: High-medium Potential for increased health issues in the future due to loss in food quality	Medium Expected impacts in the future, especially during periods of extreme heat	Good reasons to believe interventions practicable
Air quality			
Assessment of air quality and risks	Impact: Low-medium Risk of increased health issues in the future due to loss in air quality, but high for existing at-risk groups	Low-medium Expected impacts in the future	Good reason to believe intervention practicable
Water quality			
Assessment of water quality and risks from key water-borne pathogens	Impact: Medium-low Potential for increased health issues in the future due to loss in water quality	Low-medium Increased impacts expected in the future	Good reasons to believe interventions practicable
Role of water authorities	Impact: High-medium	High-medium Role of water industry will be crucial in determining success of adaptation outcomes for this and many 'downstream' sectors	
Mental health			
Mental health planning and interventions for impacts of natural disasters	Benefit: Medium-low	Low Expected impacts in the future	Good reason to believe interventions practicable
Interventions in rural communities	Benefit: Medium-low Significant activity already under way	Medium-low Drought already affecting mental health—unlikely to deteriorate markedly in short term due to climate change	Good reason to believe interventions practicable
Children's anxiety related to climate impacts	Impact: Low	Low Potential for increased incidence in the future	Interventions potentially practical but of low priority
Effect of climate change on mental health	Impact: Low	Low	Interventions potentially practical but of low priority
Community education and awareness to reduce distress	Impact: Medium	Low Potential for increased incidence in future	Interventions potentially practical but of low priority
Effects of climate change on different categories of mental health	Impact: Medium	Medium Effects of increases in extreme events	Interventions can be managed within existing mental health care structures

Potential co-benefits	Cross-sectoral relevance	Distributional justice/ Equity issues	Conclusions
Already existing risk, especially to vulnerable groups, will benefit	Relevance to Primary Industries, and Settlements and Infrastructure themes	Some groups more vulnerable	**Medium–high priority** Research required on which point in the food production–consumption chain risks arise, and how best to prevent them
Existing problems with respiratory health problems will benefit	Relevance to Settlements and Infrastructure theme	People with existing respiratory disease or vulnerability at greater risk	**Medium–low priority** Research required into levels of air quality that trigger public health interventions (e.g., air quality monitoring, public awareness)
Existing problems in vulnerable areas will benefit	Relevance to Water Resources and Freshwater Biodiversity, Settlements and Infrastructure, and Primary Industries themes	Some groups more vulnerable due to nature and location of water supply and quality of existing monitoring	**Medium priority** Development of models for effective upstream assessment of water quality, especially during drought and following extreme rainfall
	Affects downstream sectors such as primary industries, settlements etc.		**Medium–high priority** Note could be considered under Infrastructure and Services, possibly as a case study
Benefits for existing issues relating to mental health planning	Relevance to Social, Economic and Institutional Dimensions theme	Individuals with existing mental health illness at greater risk	**Medium-high priority** Some research required into effective intervention options
Economic benefits of healthy rural workforce	Relevance to Social, Economic and Institutional Dimensions theme	Rural groups more vulnerable	**Medium priority** Some research required into effective intervention options
Broader understanding of causes and treatment of anxiety	Relevance to Social, Economic and Institutional Dimensions theme	High vulnerability among children	**Low-medium priority** Some research required into effects of anxiety over climate change impacts on quality of life and future mental health
			Low priority
Broader understanding of causes and treatment of anxiety	Relevance to Social, Economic and Institutional Dimensions theme		**Low priority**
Improved environmental care	Relevance to Social, Economic and Institutional Dimensions theme	Equity considerations	**Medium priority**

Sub-theme/ Research activity	Severity/Benefit	Immediacy	Need to change intervention/ Practicality
Community and Indigenous health			
Interventions for increasing community resilience, for rural and Indigenous communities	Impact: Medium-low Potential for increased disease incidence	Medium-high Expected impacts now and in the future	Query whether climate change-specific interventions beneficial Many initiatives already under way
Impacts on Indigenous communities	Impact: Potentially high	Medium-high	Potential to reflect climate change considerations into other Indigenous community resilience programs
Intergenerational issues	Impact: Medium-low	Medium-low	Query whether interventions are required to address intergenerational issues separate from other issues
Infrastructure and services			
Integration and coordination of adaptive responses	Impact: Medium Potential for increased stress on infrastructure and services	Medium-high Expected impacts now and in the future	Good reasons to believe interventions practical—enhance mainstreaming of adaptation into health sector planning
Linkage and knowledge exchange between climate science and health practitioners for decision support	Benefit: High-medium	Medium-low Expected impacts now and in the future	Good reasons to believe interventions practical—enhance mainstreaming of adaptation into health sector planning
Role of primary health care sector	Benefit: High-medium	Medium-low Potential impacts in the future	Good reasons to believe interventions practical
Structure and staffing of health care system	Benefit: High-medium	Medium-low Expected impacts in the future	Good reasons to believe interventions practical—enhance mainstreaming of adaptation into health sector planning
Training for health care professionals	Benefit: Medium-low	Medium-low Expected impacts in the future	Good reasons to believe interventions practical
Interactions with mitigation actions	Benefit: Medium-low All adaptation strategies should be informed by need to minimise GHG emissions	Low Expected impacts now and in the future	Good reasons to believe intervention will be practical

Note: This table sets out a summarised version of the research priorities listed in Section 4.

Potential co-benefits	Cross-sectoral relevance	Distributional justice/ Equity issues	Conclusions
Existing health problems in rural and remote communities will benefit	Relevance to Settlements and Infrastructure, and Social, Economic and Institutional Dimensions themes	Some groups more vulnerable	**Medium–high priority** Some research required on effective interventions, especially for vulnerable groups
May benefit existing social issues	Relevance to Social, Economic and Institutional Dimensions themes	Major equity considerations	**Medium–high priority**
May benefit existing social issues	Relevance to Social, Economic and Institutional Dimensions themes		**Medium priority** Some research required
Existing problems in building design and codes, and health services policy will benefit	Relevance to Settlements and Infrastructure, and Social, Economic and Institutional Dimensions themes	More important for those already reliant on health system and those without alternatives to public health	**High priority** Some research required on design of coordination and integration mechanisms
Provide model of linkage mechanisms for other sectors' decision-support	Relevance to Settlements and Infrastructure, and Social, Economic and Institutional Dimensions themes		**High priority** Some research required (small project)
Existing problems in primary health care system will benefit	Relevance to Settlements and Infrastructure, and Social, Economic and Institutional Dimensions themes		**High priority** Some research required into potential role and ways to enhance
Existing issues of staffing and structure will benefit	Relevance to Settlements and Infrastructure, and Social, Economic and Institutional Dimensions themes		**High priority** Some research required into where deficiencies are
Enhanced training	Relevance to Settlements and Infrastructure, and Social, Economic and Institutional Dimensions themes		**Medium–high priority** Some research required into forms of in-career training
Enhanced mitigation efforts	Relevance to all other themes		**Low–medium priority**

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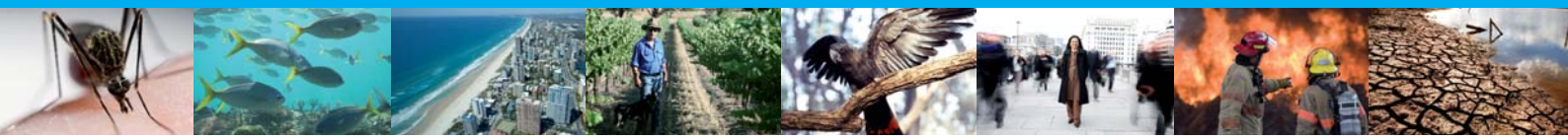

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