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Effective emissions targets needed to protect Australia's blood supply

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TAI

Policy Brief

Summary

As we become more familiar with the possible human health impacts of climate change, both the more direct (such as deaths among the elderly during a heatwave) and the less direct (such as the mental health effects of prolonged drought), we risk limiting our response capacity to those effects that are most obvious and readily attributable. The impacts of climate change will, however, extend well beyond the easily identifiable and most expeditiously modelled consequences.

Australia's proposed carbon emissions reduction target of five to 25 per cent by 2050 is insufficient to avert 'dangerous' climate change. It will lead to average warming well beyond 2°C, ensuring that significant impacts on human health will occur, especially for outcomes related to factors that are particularly climate-sensitive. Vector-borne disease[1] is highly relevant in Australia. The distribution, seasonality and abundance of vectors, as well as the disease-transmission dynamics, are strongly climate-driven.

The recent outbreak of dengue fever in Northern Queensland is illustrative of a scenario in which climate change appears to result in health consequences beyond the original impact of people sick with dengue. This outbreak caused a shortage of fresh blood products in the state, requiring donors to be sought from unaffected regions further south to boost supplies.

Without significant reductions in global greenhouse gas emissions, geographic regions with climates favourable to dengue transmission could expand to include large population centres in Western Australia, the Northern Territory, all of coastal Queensland and parts of New South Wales. During an outbreak, adequate quantities of fresh blood products could be potentially more difficult to source and maintain, with supplies in Queensland reduced by over 90 per cent and nationally by 20 per cent.

As a result of climate change, the distribution of dengue and other vector-borne diseases will be affected not only in Australia but also globally so that shortages in the supply of fresh blood products could become more widespread in the future. This situation highlights the need for Australia to adopt effective national emissions targets and support significant global reductions.

The potential for climate change to reduce blood supply in Australia also indicates that there is a need to give more consideration to a broader range of possible, but perhaps less obvious, health impacts so as to develop more comprehensive, anticipatory adaptation strategies. Ideally, these should bring both immediate benefits, before the impacts of climate change are obvious, and future benefits in a climate-changed world.

Some warming is already set in train no matter what carbon emissions reductions may be around the corner. Even the relatively small amount of warming that we are already committed to, regardless of emissions targets, requires us to plan for climate uncertainty and widespread consequences, especially for conditions such as vector-borne disease that are highly sensitive to climate. Governments will need to remain flexible in order to respond rapidly to the changing landscape and regulatory changes may need to occur well in advance of any obvious effects.

[1] Vector-borne diseases are those that are transmitted by another organism, such as a mosquito, tick, flea, or snail, rather than directly between humans.

1. Introduction

The connection between climate change and the future safety and supply of Australia's blood products is not perhaps immediately apparent. When we think of climate-change impacts on human health, we usually think first of the effects of heatwaves on the elderly and an increased exposure to vector-borne illness such as malaria. These are just two of the more obvious health outcomes expected as a legacy of climate change, where altered climatic conditions result in an increase in human illness with no steps or very few steps in between. Other likely outcomes for Australia include increases in food-borne disease,[2] and increased death and injury from more intense and/or more frequent storms, flooding and bushfires.[3] Modelling has, to date, understandably focused on outcomes that are readily measureable and for which a clear or direct relationship between climate and disease can be established.

Now, some less direct impacts are also becoming more widely recognised and studied, including:

- changes to asthma and allergy from altered seasonality and allergenicity of pollen-producing plants[4]
- reduced physical activity because of exercise discomfort in hotter temperatures[5]
- reduced intake of fresh fruit and vegetables due to crop failures and higher prices[6]
- declining mental health in rural areas as a result of the effects of prolonged drought on livelihoods and community.[7]

Not all outcomes are readily measurable and generally those with a more direct relationship to climate are easier both to detect and to measure.

Even these impacts, however, may only represent a very small portion of the overall burden of disease, ill-health or even declining social relationships resulting from climate change.

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2 H Bambrick, K Dear, R Woodruff, I Hanigan and A McMichael, 'The impacts of climate change on three health outcomes: temperature-related mortality and hospitalisations, salmonellosis and other bacterial gastroenteritis, and population at risk from Dengue'*, Garnaut Climate Change Review*, joint submission prepared by School of Medicine, University of Western Sydney and National Centre for Epidemiology and Population Health, Australian National University, June 2008. Available at: http://www.garnautreview.org.au/CA25734E0016A131/WebObj/03-AThreehealthoutcomes/$File/03-A%20Three%20health%20outcomes.pdf.

3 A McMichael, R Woodruff, P Whetton, K Hennessy, N Nicholls, S Hales, A Woodward and T Kjellstrom, *Human health and climate change in Oceania: A risk assessment, 2002*. Department of Communications, Information Technology and the Arts, 2003.

4 P J Beggs and H J Bambrick, 'Is the global rise of asthma an early impact of anthropogenic climate change?', *Environmental Health Perspective*, 113:8, pp. 915–9.

5 M Townsend, M Mahoney, J A Jones, K Ball, J Salmon, C Finch, 'Too hot to trot? Exploring potential links between climate change, physical activity and health', *Journal of Science and Medicine in Sport*, 6:3, 2003, pp. 260–265.

6 J M Dixon, K J Donati, L Pike and L Hattersley, 'Functional foods and urban agriculture: two responses to climate change-related food insecurity', *New South Wales Public Health Bulletin*: *Climate Change and Health*, 20:1–2, 2009, pp. 14–18.

7 H Berry, B, Kelly, I Hanigan, J Coates, A McMichael, J Welsh and T Kjellstrom, *Garnaut Climate Change Review: Rural Mental Health Impacts of Climate Change,* National Centre for Epidemiology and Population Health, 2008. Available at: http://www.garnautreview.org.au/CA25734E0016A131/WebObj/03-DMentalhealth/$File/03-D%20Mental%20health.pdf.

Research and modelling of health impacts are still in the early stages and, as such, can barely scratch the surface of the extent to which climate change will affect people's lives.

The evidence is gathering that in addition to refining existing models of the more direct or readily measurable outcomes, we now need to think more broadly about the *extent* and *types* of impacts so that we can develop and prioritise strategies that will provide the best chance of adapting to the changing climate as the list of possible consequences continues to grow.

Projections were recently published for regions in Australia that, because of climate change, are most likely to become exposed to dengue in the coming century,[8] one of the more obvious and direct outcomes given the influence climate has on both the mosquito vector and the transmissibility of the virus. The findings are summarised here and used to illustrate how such climate-change impacts on disease patterns could have significant 'downstream' consequences that extend far beyond the initial health outcome of interest, in this case the changing incidence of dengue infection, to the potential of climate change to reduce the supply of donated blood in Australia.

This specific case study is suggestive of just how far-reaching the health consequences of climate change might be beyond those narrowly associated with climate. Strategies for creating the best possible adaptive responses are then explored. Above all, the study demonstrates that impacts will undoubtedly extend beyond those currently predicted, thus highlighting the need for effective carbon targets to minimise adverse health outcomes.

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8 H Bambrick R Woodruff and I Hanigan, 'Climate change could threaten blood supply by altering the distribution of vector-borne disease: An Australian case-study', *Global Health Action,* 2:10.3402/gha.v2i0.2059, 2009.

2. Dengue in Australia

Dengue fever is caused by infection from one of four different types of dengue virus and is transmitted between humans by the urban freshwater mosquito *Aedes aegypti*. Local transmission occurs in most years in Northern Queensland but the virus is not yet endemic (established) in Australia. Instead, outbreaks occur when a mosquito bites an infected traveller and transmits the virus locally. Dengue infection causes fever, general aches and occasional minor bleeding. However, subsequent infection with another of the four dengue serotypes is potentially life-threatening as it can cause dengue haemorrhagic fever.[9]

From 1991 to 2007, there were 3385 confirmed cases of locally-acquired dengue fever.[10] On average, there are 200 cases a year and another estimated 120 sub-clinical cases (cases where symptoms are minor and do not result in a GP consultation).[11] Dengue outbreaks in Northern Australia are sporadic; in some years there are many cases, in others none.

The five known outbreaks prior to 1992 occurred over a 90-year period,[12] but in recent years these have become more regular with five major and many smaller outbreaks recorded between 1992 and 2004.[13] An increase in international travel into Northern Queensland and a global amplification in dengue activity, perhaps due to climate and other changes, are proposed as principal reasons for this rise in the frequency of Australian outbreaks. Sustained education and mosquito control programs instituted by public health authorities may have averted larger epidemics.[14]

The 2009 outbreak in Cairns and Townsville

An outbreak of dengue fever began in late 2008, and by early May 2009 there had been more than 900 cases recorded in and around Cairns and Townsville, with a likely additional 540 sub-clinical cases. Blood donors either resident in the region or having recently visited it were deferred, thus reducing Queensland's collection of red cells and platelets by 14 per cent over a number of months. The Australian Red Cross Blood Service (ARCBS) called for extra donations from other parts of Queensland to ensure that demand for blood supplies in the state continued to be met. In affected areas, a ban on fresh blood remains in place until no new cases have been recorded for at least three months.[15]

This is not the first time a dengue outbreak has caused a reduction in Queensland's blood collections[16] and it is unlikely to be the last.

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9 S Halstead, J Suaya and D Shepard, 'The burden of dengue infection', *Lancet* 369, pp. 1411–1412, 2009.

10 Department of Health and Ageing, National Notifiable Diseases Surveillance System (NDSS), 2008. Available from www9.health.gov.au/cda/Source/CDA-index.cfm#.

11 D Canyon, *A Review of the Dengue Mosquito, Aedes aegypti (Diptera: Culicidae) in Australia,* Tropical Infectious and Parasitic Diseases Unit, School of Public Health and Tropical Medicine, James Cook University, 2007.

12 W McBride, 'Deaths associated with dengue haemorrhagic fever: the first in Australia in over a century', *Medical Journal of Australia* 183, 2005, pp. 35–37.

13 Department of Health and Ageing, National Notifiable Diseases Surveillance System.

14 Scott Ritchie, Far North Queensland Health Service, personal communication.

15 Anthony Keller, ARCBS, personal communication.

16 Anthony Keller, ARCBS, personal communication.

The risk of transfusion transmission

Transmission of the dengue virus through blood transfusion has been documented in Hong Kong[17] and Singapore.[18] It is not known if other cases have occurred, nor how much of the virus needs to be transmitted to cause infection,[19] but the potential risk to blood supplies in endemic countries is high.[20,21]

The ARCBS collects blood from volunteer donors across Australia. Although a screening test for the dengue virus is under development, there is currently no way of testing for dengue in blood so that, even if donated by an asymptomatic person, red cells and platelets collected in an outbreak area (or from recent visitors) cannot be used. However, plasma collected from affected areas can still be used for the manufacture of blood products when it has been through the fractionation process,[22] thus limiting the shortage to fresh products only.

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17 Promed, 'Dengue virus transfusion transmission—China (Hong Kong)', 11 October 2002. Available at: http://www.slu.edu/colleges/sph/csbei/emerginginfections/dengue/news/dengue101102a.pdf.

18 P A Tambyah, E S C Koay, M L M Poon, R V T P Lin and B K C Ong, 'Dengue Hemorrhagic Fever transmitted by blood transfusion', *New England Journal of Medicine*, 359:14, 2008, pp. 1526–7. Available at: www.nejm.org.

19 L H Chen and M E Wilson, 'Transmission of dengue virus without a mosquito vector: nosocomial mucocutaneous transmission and other routes of transmission', *Clinical Infectious Diseases* 39, 2004, pp. e56–60.

20 H Mohammed, J M Linnen, J L Munoz-Jordan et al., 'Dengue virus in blood donations, Puerto Rico, 2005', *Transfusion* 48:7, 2008, pp. 348–54.

21 J M Linnen, E Vinelli, E C Sabino, L H Tobler, C Hyland, T H Lee, D P Kolk, A S Broulik, C S Collins, R S Lanciotti and M P Busch, 'Dengue viremia in blood donors from Honduras, Brazil, and Australia', *Transfusion* 48, 2008, pp. 1355–62.

22 Anthony Keller, ARCBS, personal communication.

3. Impacts of climate change on dengue

This paper presents the modelled changes to the geographic areas and numbers of people at risk from dengue fever under four possible climate-change scenarios (Box 1).

An empirical model[23] of the relationship between climate and dengue, based on the current known global presence of dengue outbreaks, was applied to determine geographic areas at risk of the disease in the future. The climate factor that predicts the presence of dengue most accurately is the long-term average humidity of a region expressed as 'average annual vapour pressure' (for the baseline climate period 1961–1990), which is an expression of both humidity and temperature. Mosquito survival is strongly dependent on moisture and humidity levels; warmer temperatures, especially with higher humidity, result in longer mosquito life spans and an increased likelihood of multiple blood feeds and hence of transmission. Importantly, warmer temperatures also facilitate the transmissibility of the virus due to its faster replication rate within the mosquito, and this reduces the time between when a mosquito becomes infected and when it can transmit the virus. The model does not attempt to predict the current or potential geographic range of the vector itself, which may extend well beyond regions that are currently conducive to virus transmissibility—it is a model of the climate-disease relationship and not that of the vector.

This climate-disease relationship was used to model the regions in Australia that would become high risk for dengue transmission under different climate-change scenarios. We estimated the probability that one (or more) epidemics of dengue fever could occur, defining regions to be 'at risk' of dengue only conservatively where the model indicated a greater than 50 per cent probability of transmission.

Box 1. Climate scenarios

The four climate scenarios were produced by Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO) for *The Garnaut Climate Change Review*.[24]

Three of the scenarios assume that 'no action' is taken to reduce emissions, which thus remain high and continue to rise with global temperature increasing to around 4.5°C by 2100. These scenarios differ according to anticipated changes in humidity and precipitation.

The fourth scenario assumes 'strong action' is taken; emissions are significantly reduced over coming decades, CO_2 stabilises at 420ppm by 2100, and mean global temperature increase is around 2°C. The results for this emissions scenario are the same for all humidity levels that were also included in *The Garnaut Review*.

	No action			**Strong action**
Scenario	**1** Hot and dry	**2** Hot, median humidity	**3** Hot and wet	**4** Warm
Global average temperature increase	~4.5˚C	~4.5˚C	~4.5˚C	~2˚C
Humidity	Low	Median	High	Median

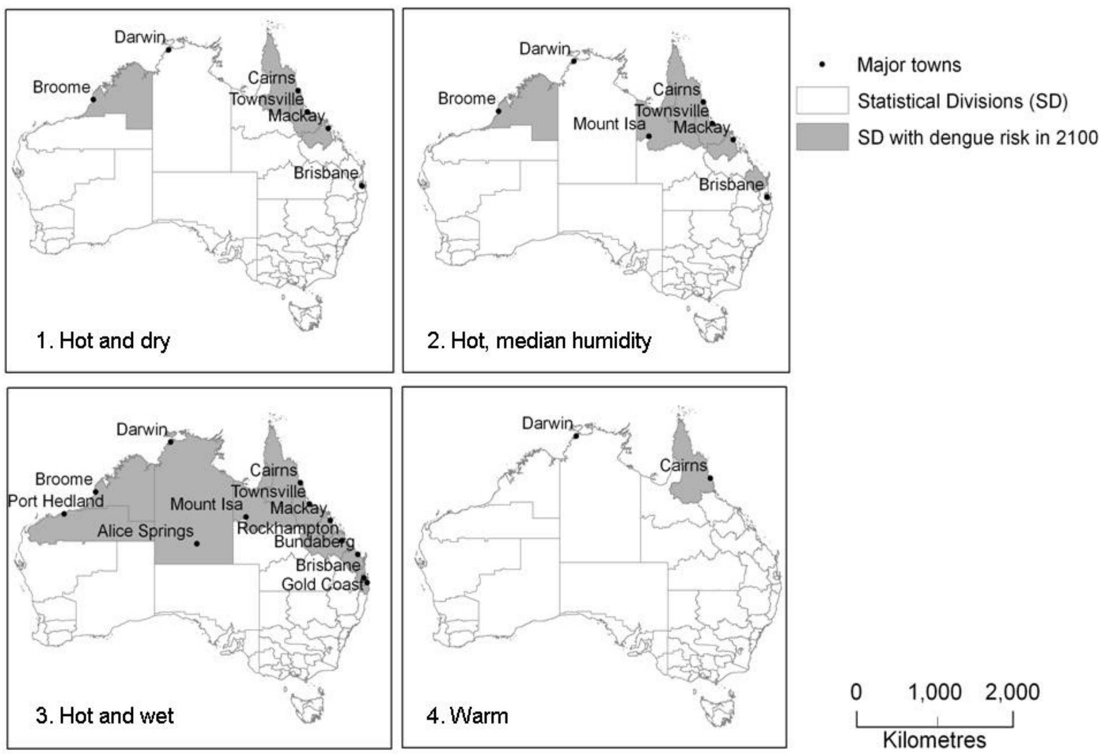
23 S Hales, N de Wet, J Maindonald and A Woodward, 'Potential effect of population and climate changes on global distribution of dengue fever: An empirical model', *Lancet* 360:9336, 2002, pp. 830–4.

24 R Garnaut, *The Garnaut Climate Change Review Final Report*, CUP, Melbourne, 2008.

Extended transmission regions

Under each of the three scenarios that were based on ‘no action’ towards reducing emissions, there is an increase in the geographic area and hence the number of Australian statistical divisions that will become favourable to dengue transmission (Figure 1). In Scenario 3 (Hot and wet), the geographic region at risk stretches both far south and west from its current distribution and includes all coastal areas of Queensland extending into New South Wales, northern Western Australia and the Northern Territory. In Scenarios 1 (Hot and dry) and 2 (Hot, median humidity), dengue transmission areas reach south in Queensland to include Brisbane (and in Scenario 2 west to Mt Isa), and into Broome in Western Australia. By contrast, the ‘strong action’ Scenario 4 (Warm), with only 2°C average global warming, shows dengue transmission-suitable areas remain limited to Northern Queensland and to Darwin.

Figure 1: Areas suitable for dengue transmission under four climate change scenarios.



Note: These estimates are conservative, including only those areas that indicate a more than 50 per cent chance of being transmission-suitable; there is still a chance of dengue transmission outside the predicted regions.

Population at risk

We estimated the numbers of people at risk in coming decades under each scenario using population projections for each statistical division,[25,26] with the results shown in Figure 2. The

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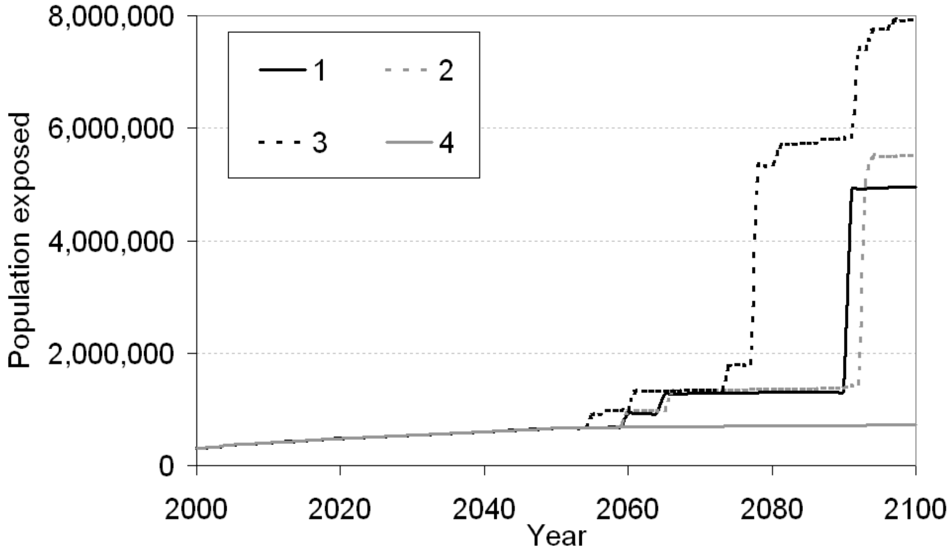
25 Australian Bureau of Statistics and Space-Time Research Pty Ltd, *Population Projections of Australia (Series A, B and C) by Part of State and Single Year of Age (85+) and Sex, 2004–2051*, Cat. No. 3222.0, Table 1, Canberra, 2005. Available at: http://www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/3222.02004%20to%202101?OpenDocument.

increase observed for the next four decades is gradual and due solely to expected population growth in existing dengue regions rather than to a geographic expansion of transmission-suitable areas. Around mid-century, however, step-changes occur under each of the three 'no action' scenarios as a result of geographic expansion incorporating new population centres.

Figure 2: The number of people living in regions suitable for dengue transmission under different climate-change scenarios.



Note: 1= Hot (dry); 2=Hot (median humidity); 3=Hot (wet); 4= Warm.

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[26] Australian Bureau of Statistics and Space-Time Research Pty Ltd, *Population Projections of Australia (Series A, B and C) by Single Year of Age (100+) and Sex, 2004-2101*, Cat. No. 3222.0, Canberra, 2005. Available at: http://www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/3222.02004%20to%202101?OpenDocument.

4. Impact on Australia's blood supply

Modelling of the population at risk of dengue infection in the future suggests that blood supply shortages may become more severe and widespread due to the expansion of the geographic regions where transmission is likely to occur, especially if strong emissions reduction targets are not implemented. At the same time, the numbers of people living in dengue-risk areas will increase due to population growth.

We used the current proportions of 'regular' donors from each state to estimate future percentage declines in national blood supply based on modelled dengue-transmission areas, 'population at risk' and projected incidence of infection. Blood donation contribution by state and territory was estimated from a recent national survey of over 2000 adults[27] where the response was 'usually donate at least every 6 months'.

As reductions in blood supply during an outbreak are geographically determined, the proportion of the population in each state living in transmission-risk zones relates directly to the potential decline in blood supply in each state during an outbreak, assuming that blood donors are evenly distributed throughout the population of each state.

The estimated future proportion of each state's population living in transmission-risk areas in selected years is shown in Table 1. The effect of climate change on the regional and national contributions to Australia's blood supply was then estimated for each state by multiplying the proportion of its population by its contribution to blood supply (Table 2).

Table 1: Proportion of the population within each dengue-risk state living in transmission areas under the four scenarios.

		Proportion of state/territory population living in dengue-risk areas			
Scenario	**State/territory**	**2020**	**2050**	**2070**	**2100**
Hot and dry	Queensland	0.06	0.06	0.15	0.61
	Western Australia	-	-	0.02	0.02
	Northern Territory	0.46	0.46	0.46	0.46
Hot (median humidity)	Queensland	0.06	0.06	0.15	0.69
	Western Australia	-	-	0.02	0.02
	Northern Territory	0.46	0.46	0.46	0.46
Hot and wet	Queensland	0.06	0.06	0.15	0.93
	Western Australia	-	-	0.02	0.04
	Northern Territory	0.46	0.46	0.46	1.00
	New South Wales	-	-	-	0.03
Strong mitigation	Queensland	0.06	0.06	0.06	0.06
	Northern Territory	0.46	0.46	0.46	0.46

Note: This proportion is extrapolated from the current pattern of residence and no allowances have been made for future variation in internal migration.

[27] H Bambrick, J Fear and R Denniss, *What does $50,000 buy in a population survey? Characteristics of internet survey participants compared with a random telephone sample*, Technical Paper No. 5, Canberra, The Australia Institute, 2009.

Table 2: Projected decline in blood supply in Australian states and territories with high-risk transmission regions, and nationally.

		Decline in state's blood supply during an outbreak (%)				Total national decline in blood supply (%)			
Scenario	State/territory	2020	2050	2070	2100	2020	2050	2070	2100
Hot and dry	Queensland	6	6	15	61	2	2	3	12
	Western Australia	-	-	2	2				
	Northern Territory	46	46	46	46				
Hot (median humidity)	Queensland	6	6	15	69	2	2	3	14
	Western Australia	-	-	2	2				
	Northern Territory	46	46	46	46				
Hot and wet	Queensland	6	6	15	93	2	2	3	20
	Western Australia	-	-	2	4				
	Northern Territory	46	46	46	100				
	New South Wales	-	-	-	3				
Strong mitigation	Queensland	6	6	6	6	2	2	2	2
	Northern Territory	46	46	46	46				

The results presented above show that blood supply in Queensland and the Northern Territory will be most affected. Projections of declines for Queensland show at least 15 per cent in the decades before the end of the century and between 61 and 93 per cent at a minimum by the end of the century. In the Northern Territory, the projected decline will be 100 per cent by the end of the century. Such losses will occur at least periodically if transmission patterns do not intensify.

5. The case for mitigation

If insignificant action is taken to reduce global carbon emissions, the distribution of dengue transmission-suitable areas could, at the very least, progress southward along the Queensland coast and include the northernmost parts of Western Australia. Under wetter conditions, transmission-suitable areas could extend into New South Wales along the east coast, as far south as Port Hedland in Western Australia and well into the Northern Territory. If several dengue outbreaks were to occur spontaneously in different areas or spread between the newly transmission-suitable regions, blood collections and potentially the future supply of fresh blood products could be greatly reduced across the country, proportionate to the populations of the affected regions.

People living in towns and cities never before exposed to dengue would be particularly susceptible during outbreaks and a larger proportion of the population could become infected, increasing the amount of virus circulating and thus heightening the risk of transmission. This situation would be likely to intensify the probable impacts on blood supply by prolonging the epidemic. As an example, an estimated 26 per cent of the population were infected in one outbreak that occurred in the Queensland town of Charters Towers in 1993.[28]

The altered distribution of dengue modelled here is predicted to reduce Queensland's blood supply by between 61 per cent and 93 per cent by the end of the century unless strong mitigation action is taken, although such reductions may remain periodic providing dengue does not become endemic to an area. Changing transmission intensity was not modelled but it is a likely outcome of climate change, especially in regions that become more humid or where minimum temperatures (night-time or winter-time) are not sufficiently low to disrupt either vector activity or replication of the virus.[29] Again conservatively, we estimate that blood supply in the Northern Territory could be reduced by more than double the current potential periodic loss, and Australia's national supply by up to 20 per cent. Larger reductions in Queensland's blood supply are likely to occur earlier than modelled here as some years will almost certainly experience outbreaks outside these boundaries.

Other vector-borne viruses

The potential for climate change to reduce future blood supply is not restricted to the likely increase in dengue virus; a number of other vector-borne pathogens could be similarly affected. The transfusion-transmissibility of the viruses of importance to Australia, including Ross River virus, Barmah Forest virus and Murray Valley Encephalitis, is currently unknown.[30] During December 2008, there were 470 cases of Ross River virus and Barmah Forest virus combined, with the majority occurring in Queensland.[31] Outbreaks of these viruses are also expected to increase in incidence, intensity and geographic distribution as conditions become more favourable to mosquitoes, a situation that could have further detrimental impacts on blood supply.

Blood shortages and safety hazards resulting from climate change could also become a significant and long-term issue beyond Australia's borders, especially in regions already

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[28] W J H McBride, H Mullner, J T LaBrooy and I Wronski, 'The 1993 dengue 2 epidemic in Charters Towers, North Queensland: clinical features and public health impact', *Epidemiology and Infection*, 121, 1998, pp. 151–156.

[29] Jetten, T H and Focks, D A (1997). 'Potential changes in the distribution of dengue transmission under climate warming', *American Journal of Tropical Medicine and Hygiene*, 57:3, pp. 285–97.

[30] R Dunstan, C Seed and A Keller, 'Emerging viral threats to the Australian blood supply', *Australian and New Zealand Journal of Public Health* 32, 2008, pp. 354–60.

[31] Department of Health and Ageing, National Notifiable Diseases Surveillance System.

struggling to control vector-borne disease or those that are on the margins of current distribution. The incidence of dengue is increasing in parts of the Americas and Asia and the warmer temperatures associated with climate change are expected to enhance its transmission in those areas already affected[32,33] and to increase the probability of its emergence in new areas.[34] As in Australia, climate-change impacts on other vector-borne diseases could contribute to future blood shortages across the globe. The recent emergence of chikungunya in northern Italy caused a reduction in blood supply and plasma for manufacture.[35] Dengue and other vector-borne diseases such as West Nile virus are becoming established in previously unaffected regions.[36,37]

Further, the increasing global movement of blood and blood products has several serious consequences. The disease risk is no longer contained geographically to an already affected region but can potentially lead to local transmission in a previously unaffected area, and any contaminated supplies are becoming both harder to trace and recall.

The recent epidemic in Queensland proved particularly difficult to control, which may be symptomatic of climate changes that have already occurred. By mid-century, rather than merely increasing the frequency or amplitude of outbreaks in already affected areas, the impact of climate change on expanding dengue-transmission *regions* in Australia and elsewhere will become obvious.

It may be by this time that medical therapies will no longer rely on donated blood, that dengue will have become readily treatable, or that an accurate and reliable screening test will have become available. The development of an effective dengue vaccine and/or the future application of pathogen-reduction technology to blood components may also mitigate the risks. However, even if such technologies are in place, there remains a large number of other vector-borne pathogens of importance to Australia that will be similarly affected by climate change. If the current situation for screening, vaccination, and reliance on blood products holds for the future, the availability of fresh blood products could be reduced unless blood collections can be adequately increased in non-affected areas.

With its national control of blood-component inventory, Australia is well-placed to manage by moving blood components into areas of need as required.[38] But, depending on the geography, timing or intensity of future outbreaks, this capacity to make up for losses in one area of the country by obtaining products from another could be reduced by climate change. Other regions of the world are not so lucky and do not have similar safety nets that can be invoked when outbreaks occur. With climate change expected to affect a number of vector-borne

32 P L Bultó, A P Rodríguez, A R Valencia, N L Vega, M D Gonzalez and A P Carrera, 'Assessment of human health vulnerability to climate variability and change in Cuba', *Environmental Health Perspectives*, 114:12, 2006, p. 1942.

33 M R Jury, 'Climate influence on dengue epidemics in Puerto Rico', *International Journal of Environmental Health Research* 18:5, 2008, pp. 323–334.

34 E A Gould, S Higgs, A Buckley and T S Gritsun, 'Potential Arbovirus Emergence and Implications for the United Kingdom', *Emerging Infectious Diseases* 12, 2006, pp. 549–555.

35 G M Liumbruno, D Calteri, K Petropulacos et al., 'The Chikungunya epidemic in Italy and its repercussion on the blood system', *Blood Transfusion*, 6:4, 2008, pp.199–210.

36 A Jansen, C Frank, J Koch and K Stark, 'Surveillance of vector-borne diseases in Germany: trends and challenges in the view of disease emergence and climate change', *Parasitology Research* 103, Suppl 1, 2008, pp. S11–7.

37 E A Gould and S Higgs, 'Impact of climate change and other factors on emerging arbovirus diseases', *Transcripts of Research on Social and Tropical Medicine and Hygiene* 103:2, 2009, pp. 109–21.

38 Anthony Keller, ARCBS, personal communication.

infections worldwide, periodic or even continuous shortfalls in blood supply could be expected, together with an increase in transfusion-transmission risk.

6. Australia's emissions reduction targets

Over coming decades, climate in Australia and elsewhere will be shaped by future global carbon emissions. Emissions levels will be heavily dependent on the action taken by national governments, especially those of currently high-polluting countries such as Australia and those with large populations that are rapidly industrialising such as India and China.

While some climate change is already underway, strong emissions reductions could avert global average warming of greater than 2°C, the threshold of 'dangerous' climate change,[39] and the only level of warming shown by our modelling not to increase significantly the geographic areas suitable for dengue transmission in Australia. Even this relatively modest level of warming, however, will probably change transmission dynamics and intensify infection within already affected areas, given how sensitive both the vector and pathogen are to climate.

The five to possibly 25 per cent target for emissions reductions by 2020 announced in May 2009 by the Australian Government is well below the 40 to 50 per cent global reduction estimated to be the minimum required to stabilise CO_2 emissions below 450ppm and warming below 2°C.[40] The latest emissions data show that the world is tracking above even the highest emissions scenarios that were modelled by the most recent Intergovernmental Panel on Climate Change,[41] with a global average warming of 4°C now expected by mid-century.[42] As one of the highest per capita producers of carbon emissions in the world, Australia needs to aim for a higher percentage of emissions reductions than the global mean target of 50 per cent

Without strong and urgent action by national governments, dengue-favourable conditions will most likely spread throughout Queensland, the Northern Territory and into Western Australia and New South Wales. There will be similar impacts elsewhere in the world both for dengue and other vector-borne diseases. The smaller increases in temperature that are presently occurring may already be affecting the transmission of vector-borne disease.

Importantly, as demonstrated perhaps by the recent epidemic of dengue in Far North Queensland, outbreaks of vector-borne disease will become more difficult to control as the climate changes. Regions under disease surveillance may need to respond rapidly with control measures implemented swiftly. Regulatory action to reduce potential breeding habitats, such as adequate screening of water tanks to inhibit oviposition by mosquitoes, should be considered well in advance.

It is difficult when assessing the impacts of climate change on health outcomes to predict precise adjustments in occurrence or distribution, and this is especially true for vector-borne diseases where innumerable environmental, human and other animal behaviours and

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[39] Intergovernmental Panel on Climate Change (IPCC), *Climate change 2007: Synthesis report*, Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, Pachauri, R.K and Reisinger, A. (eds.)], IPCC, Geneva, Switzerland, 2007. Available at: http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr.pdf.

[40] Intergovernmental Panel on Climate Change (IPCC), *Climate change 2007: Synthesis report.*

[41] M Raupach, N Gruber and J Canadell, 'The global carbon cycle', in Richardson, K et al.,(eds.), *Synthesis Report*, from IARU International Scientific Congress on Climate Change: Global Risks, Challenges & Decisions, Copenhagen, 10–12 March, University of Copenhagen, 2009.

[42] R Betts, M Sanderson, D Hemming et al., *4 degrees C warming: Regional patterns and timing,* 4 Degrees and Beyond International Climate Conference, Oxford, Oxford University, September 2009.

physiologies are involved.[43] The example of how climate change could affect the supply of blood in Australia by extending the range of dengue-favourable environments illustrates what should be a significant concern to Australia and highlights the importance of taking as broad a view as possible when assessing likely climate-change impacts.

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43 R W Sutherst, 'Global change and human vulnerability to vector borne diseases', *Clinical Microbiology Reviews*, 17, 2004, pp. 136–73.

7. Adaptation planning to deal with far-reaching effects

The nature of climate-change consequences in Australia and elsewhere is likely to extend well beyond our current imaginings. In many cases, health impacts will be difficult to tease out from social or technological change that may be occurring independently. In particular, care must be taken that strategies intended to be adaptive to climate change do not in fact contribute to adverse health impacts. One example where this may have already occurred is the widespread household installation of water tanks to help cope with prolonged drought, which provide more potential mosquito-breeding habitats.[44]

An adequate approach to adaptation aimed at minimising unintended and adverse consequences will require a thorough understanding of numerous and interlinking ecological, social, economic, physiological, epidemiological and technological factors. While we cannot predict the full range of impacts, interdisciplinary research needs to be combined with broad, visionary reasoning to find the best way of avoiding adverse side-effects.

Co-benefits of adaptation

The threat of climate change could in fact be an important driver of adaptive strategies that bring significant and immediate health benefits, regardless of the eventual outcomes of climate change. Such 'co-benefits' are a relatively recent consideration in climate-change mitigation and are intended to be 'win-win' strategies, providing benefits even in the absence of climate-change effects. One example is the development of clean-energy technologies such as renewables that serve not only to reduce greenhouse gas emissions in the medium and long term but also to improve air quality in the short term, with consequent immediate health benefits.[45] Another is reducing the reliance on private transport to both improve air quality and increase people's physical activity.

Strategies for climate-change adaptation, rather than mitigation alone, could also consider immediate co-benefits for human health. For example, retro-fitting housing with insulation to limit rising energy consumption costs has the additional and immediate health benefit of reducing thermal stress in extreme heat or cold.

Similarly, there could be significant co-benefits in taking prompt action to safeguard Australia's blood supply against climate change. Some suggestions include:

- The introduction of regulatory changes that allow for blood to be readily sourced from elsewhere during a prolonged or widespread outbreak, with the co-benefit of providing a readily available alternative source should there be another reason of need (such as contamination or breakdown in supply). Australia's National Blood Agreement already allows for the movement of blood between states during periods of local or statewide shortages.

  As a large and climatically diverse country, this within-country movement may generally be sufficient. However, if outbreaks of a number of viruses with different environmental niches happen to occur at the same time, or if climate change facilitates the spread of dengue into New South Wales and the Northern Territory, or there is a widespread outbreak of a novel infectious disease (such as a new strain of influenza), there could be a risk of national

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[44] N W Beebe, R D Cooper, P Mottram and A W Sweeney, 'Australia's dengue risk driven by human adaptation to climate change', *PLoS Neglected Tropical Disease* 3:5, 2009, p. e429.

[45] K R Smith and E Haigler, 'Co-benefits of climate mitigation and health protection in energy systems: scoping methods', *Annual Review of Public Health* 29, 2008, pp. 11–25.

shortages. An established agreement with other countries with similar safety standards could facilitate the supply of an alternative source.

- The development of universal screening for dengue and other mosquito-borne viruses among blood donors. Aside from protecting recipients, screening would have the co-benefit of assisting with the detection and surveillance of outbreaks, as well as identifying early any increase in geographic range, unusual levels of virus activity, or change to usual seasonality. This could provide valuable information for timely mosquito control and public education, for example. A screening test for dengue is currently under development[46] but would not, however, be able to pick up the emergence of novel viruses or those for which no screening test is yet available.
- The increasing incidence and spread of dengue and other viruses worldwide could speed up the development of synthetic products, which could bring a number of co-benefits if successful, including:
    - reducing reliance on a dwindling donor base; the number of people who are regular blood donors is in decline relative to the increasing demands on blood products[47]
    - negating any ethical and public health concerns regarding payment that is made to donors in some countries (for example, the exploitation of paid donors and the higher risk of infection with blood from paid donors),[48] and eliminating the global trade of blood from poor to rich countries[49]
    - eliminating seasonal shortages due to influenza and other infections.

In the development of strategies aimed at climate-change adaptation, the principal goal is to deliver multiple benefits while avoiding or at least minimising any risk of adverse outcomes. This suggests that both the development and implementation of adaptation strategies must be carefully considered and include a broad range of stakeholders and experts to maximise the co-benefits and minimise the risk that poorly thought out and too hurriedly implemented solutions could introduce unintended adverse consequences.

Of course, those forming adaptive responses to climate change may not always have the luxury of time. Some threats may need to be dealt with rapidly and decisively, with more broad-ranging discussion to follow. Extreme weather events, for example, can arise quickly and with little warning and while they are already expected to become more frequent and more intense with climate change, we cannot yet predict their timing and location. But the fact of these events should not come as a surprise and could, to some extent, be planned for in advance. This uncertainty provides further reason to take preventive action to minimise climate-change impacts by legislating for effective emissions reduction.

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46 Anthony Keller, ARCBS, personal communication.

47 P Flood, P Wills, P Lawler et al., *Review of Australia's Plasma Fractionation Arrangements*, Commonwealth of Australia, Canberra, 2006. Available at: http://www.health.gov.au/internet/wcms/publishing.nsf/Content/plasma-fractionation-review-overview.htm.

48 C L van der Poel, E Seifried and W P Schaasberg, 'Paying for blood donations: Still a risk?', *Vox Sang* 83:4, 2002, p. 285–293.

49 P Volkow, Y Lopez-Vidal, R I Amieba and M Hernandez, 'Paid plasma donation and risk of blood-borne diseases in blood-product recipients', *Lancet* 358:9297, 2001, pp. 2001–2.

Climate change will not affect all regions equally. Possibly, the best adaptive strategies will be developed at the community level, at least in the first instance, to respond most appropriately to local problems as they become apparent and to identify potential risks and co-benefits. As small communities are unlikely to have access to the necessary range of interdisciplinary expertise, a formal system for expert review of local ideas may be beneficial.

It may be that national or state-based planning is best for those impacts that are most readily foreseeable, such as heat-related deaths, while detailed implementation strategies could be devised more at a local level.

Model limitations

The predictive model we employed in our analyses is conservative; only areas that were deemed to have a greater than 50 per cent chance of transmission were considered 'a risk'. The model predicts current global dengue presence with an accuracy of 89 per cent based on areas deemed to have a greater than 50 per cent chance of transmission.[50] The implication is that some regions returning a lower than 50 per cent probability estimate in the model could still be suitable for dengue transmission, including Townsville where the most recent Australian outbreak occurred.

Neither does the model look at possible changes to the *intensity*, *length* or *frequency* of outbreaks, instead focusing only on the geographic regions. It is expected that as a consequence of climate change, any given outbreak may become more difficult to control—more people may become infected, the outbreak may last longer, and outbreaks may occur more often. It may also mean that previously epidemic areas become endemic for dengue so that an outbreak need not be triggered by an infected traveller but could be initiated locally.

The model we used does not predict *vector* distribution but rather regions suitable for future *virus transmission*, based on parameters that define current known transmission regions. Vectors do exist, and have probably existed in the past, in regions where transmission does not currently occur.[51] Importantly, the model is defined by the effects of current human behaviour, such as surveillance programs that have kept dengue from being more widespread in recent years than it otherwise might be. It is also informed by existing rather than future urban features and infrastructure, such as water reticulation that has reduced domestic water storage and thus *Aedes aegypti* breeding sites. Beebe et al. have suggested that human adaptation to climate change may in fact cause further spreading of the *Aedes* mosquito in Australia and more intense epidemics as prolonged water shortages have already led to increases in the installation of domestic water tanks.[52]

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[50] Hales, 'Potential effect of population and climate changes on global distribution of dengue fever'.

[51] Beebe et al., 'Australia's dengue risk'.

[52] Beebe et al., 'Australia's dengue risk'.

7. Conclusion

The shortage of fresh blood products in Australia is only one of the possible human-health consequences of climate change, but it is suggestive of the breadth of likely impacts beyond current modelling.

Mitigation is the best strategy for minimising the potentially broad climate-change impacts on human health. Emissions reduction targets will need to be strong and their implementation effective to avoid significantly extending the geographic range of dengue transmission in Australia.

Just as action to reduce greenhouse gases could bring substantial and immediate benefits to health, well-planned adaptation strategies to safeguard blood supply could have multiple benefits even in the absence of adverse climate-change impacts.

The human health consequences of climate change are likely to be many and highly varied, and will place an additional burden on state health budgets. The public health costs of climate change and the costs of adaptation will largely fall to the states and territories, yet the revenue that is proposed to be collected under the Federal Government's Carbon Pollution Reduction Scheme (CPRS) is not earmarked for either state health budgets or adaptation assistance.

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