Garnaut Climate Change Review

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

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1 Overview

Climate change will affect the health of Australians over this century in many ways. Some impacts will become evident before others. Some will occur via quite direct pathways (e.g. heatwaves and death); others will occur via indirect pathways entailing disturbances of natural ecological systems (e.g. mosquito population range and activity) or disruption to livelihoods and communities (e.g. mental health consequences of prolonged droughts and regional drying trends). Most health impacts will occur at different levels among regions and population sub-groups, reflecting the influence of environment, socioeconomic circumstances, infrastructural and institutional resources, and local preventive (adaptive) strategies on the patterns of disease.

The likely health impacts are many and varied. The main health risks in Australia from climate change include:

- health impacts of weather disasters (floods, storms, cyclones, bushfires, etc.)
- health impacts of temperature extremes, including heatwaves
- mosquito-borne infectious diseases (e.g. dengue fever, Ross River virus disease)
- food-borne infectious diseases (including those due to *Salmonella*, *Campylobacter* and many other microbes)
- water-borne infectious diseases, and other health risks from poor water quality
- diminished food availability: yields, costs/affordability, nutritional consequences
- increases in urban air pollution (e.g. ozone), and the interaction of this environmental health hazard with meteorological conditions
- changes in aeroallergens (spores, pollens), potentially exacerbating asthma and other allergic respiratory diseases
- mental health consequences of social, economic and demographic dislocations (e.g. in parts of rural Australia, and via disruptions to traditional ways of living in remote Indigenous communities)

At this stage of research and understanding, and in context of available time and resources, it is only possible to include a minority of those anticipated health impacts in this quantitative modelling exercise.

1.1 Health risks assessed in this review

This assessment estimates the health and workforce costs of three health outcomes:

- temperature-related deaths and hospitalisations
- gastroenteritis caused by *Salmonella* and other bacteria
- dengue fever, a mosquito-borne viral infection.

These three were chosen because the mechanism by which climate affects each health outcome has been well documented by peer-reviewed research. We were able to apply existing or readily determined climate-health relationships to the prescribed scenarios of future climate change in Australia.

Although they illustrate the potential scale of climate change impacts on health, we judge these three outcomes account for not more than one half of the climate-related deaths that are likely to occur from the list above. In view of the likely substantial size of the total future burden of poor health from climate change, these three selected impacts may account for no more than one third of the total definable burden (comprising significant acute events, chronic disabling conditions, and premature deaths). That total burden would include, among other causes, mental health disorders (depression, anxiety and post-traumatic stress disorders), infections from diverse climate-sensitive infectious diseases (including mosquito-borne infections such as Ross River virus, Barmah Forest virus, and Murray Valley Encephalitis—each likely to display changes in geographic range, prolonged seasons, and/or higher peaks in transmission), and the health consequences of nutritional deficits in vulnerable sub-groups.[1]

On the current incomplete evidentiary basis, it remains uncertain how many other conditions may respond to climatic changes, or these responses are yet able to be expressed mathematically. We do not know the range and distribution of health-losses attributable to mental health consequences of job loss, property loss, displacement, post-traumatic stress, childhood anxieties, for example. Nor do we know the extent of adverse health outcomes (deaths, injuries, infections, stress disorders, etc.) from extreme weather events, for which in all likelihood there will be significant variations, depending on location and intensity and on the infrastructure and state of preparedness of exposed communities. For instance, there is substantial evidence that air quality is affected by meteorological conditions, but, as of yet, we cannot quantify this in relation to incremental health risks. Similar constraints also apply to aeroallergens (pollens, spores, etc.), which are expected to increase in atmospheric concentration in some regions of Australia over coming decades.

The total health burden in human terms may not be commensurate with economic costs. A premature death from a heatwave can occur quickly and in an older person no longer in the workforce; a significant human cost but not necessarily one rating highly in market terms. In contrast, a three-day episode of diarrhoea in a working-age adult will cause some discomfort and distress, soon be overcome, and yet weigh heavily on lost-productivity.

1.2 Measures of health impacts, and relevance to economic modelling

Health outcomes of environmental exposures/conditions can be measured as numbers of events (deaths, hospitalisations, primary health-care consultations), as estimates of time spent with suffering or disability, as estimates of the duration of healthy life lost (including from premature death), or as estimates of economic costs incurred.

The last-mentioned econometric approach comprises several possible types of measure:

- estimated inherent value of good health and of survival (avoidance of premature death)—assessable via survey research, assessing contingent value, or willingness-to-pay
- direct costs incurred by the health-care system: diagnosis, treatment, care
- lost workplace productivity from days off work, long-term reductions in work capacity, and premature death of skilled workers
- costs incurred by public health surveillance, prevention and control activities, in order to lessen or avert the above events and associated costs.

In order to extend the estimation of population health impacts from climate change into robust estimates of economic costs, it is necessary to have good-quality and sufficiently detailed information on age-specific risks to health, on age-specific levels of disability and lost workplace availability, and on the component costs of items 2 and 4 above. In general, there are reasonable average data available in Australia for this purpose. Nevertheless, there are future information and research tasks to be undertaken to improve the scope and accuracy of the modelling of economic-related health outcomes.

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[1] In this context, “total burden” is not an economic parameter but refers to human physical and psychological loss The term is widely used internationally in relation to the summation of adverse health outcomes, generally used to refer to the aggregation of premature deaths, chronic disabling health consequences, and, sometimes, the contributions of acute episodes (such as an episode of diarrhoeal disease).

1.3 Extreme events and climate variability

Future weather is expected to become more extreme in its pattern,[1] with storms, floods and bushfires increasing in frequency and intensity, cyclones becoming more intense, and prolonged and intense heatwaves. The modelled climate change scenarios used for this assessment do not include estimates of future changes in the variability of climate. This reflects the fact that, at the current state of development of climate change modelling, future changes in climate variability are more difficult to model than are changes in average conditions.

Speaking generally, we expect there will be an increase in the amount of injury and death and, less directly, health and well-being through the loss of property and livelihoods. However, this assessment is not able to undertake a specific economic estimation of the health costs of additional extreme weather. This causes an under-estimation of future health impacts of climate change. We judge that the estimates we have provided of the impact of climate change on heat-related deaths and hospitalisations, and on food-poisoning, are quite conservative, perhaps substantially so.

1.4 Future adaptation

It is most likely that people will adapt to the forthcoming changes in climate in physiological, behavioural, institutional and technological ways. There are geographical differences in deaths from heatwaves, for example, which suggest that over time people become accustomed to the climate in which they live and adapt as best they are able.

This assessment does not quantify the extent to which future adaption to climate change will modify the levels of death, injury and ill-health for each health outcome. It will be difficult to make confident quantitative assumptions about the potential adaptive consequences of climate change for several decades hence, given the path of global and local responses to mitigating climate change has yet to be taken.

1.5 Climate scenarios

The seven climate change scenarios prepared for the Garnaut Review were used in the health analyses:

No-mitigation scenarios

Unmitigated Scenario 1 (U1)—Hot, dry scenario, using A1FI emissions path, 10th percentile rainfall and relative humidity surface for Australia (dry extreme), 90th percentile temperature surface. Mean global warming reaches ~4.5℃ in 2100.

Unmitigated Scenario 2 (U2)—*Best estimate* (median) scenario using A1FI emissions path, 50th percentile rainfall and relative humidity surface for Australia, 50th percentile temperature surface. Mean global warming reaches ~4.5℃ in 2100.

Unmitigated Scenario 3 (U3)—Warm, wet scenario using A1FI emissions path, 90th percentile rainfall and relative humidity surface for Australia (wet extreme), 50th percentile temperature surface. Mean global warming reaches ~4.5℃ in 2100.

Global mitigation scenarios

Mitigation Scenario 1 (M1)—Dry mitigation scenario where stabilisation of 550 ppm CO_2 equivalent (CO_2 stabilised at 500 ppm) is reached by 2100, 10th percentile rainfall and relative humidity surface for Australia (dry extreme), 90th percentile temperature surface. Mean global warming reaches ~2.0℃ in 2100.

Mitigation Scenario 2 (M2)—*Best estimate* (median) mitigation scenario where stabilisation of 550 ppm CO_2 equivalent (CO_2 stabilised at 500 ppm) is reached by 2100, 50th percentile rainfall and relative humidity surface for Australia, 50th percentile temperature surface. Mean global warming reaches ~2.0℃ in 2100.

Mitigation Scenario 3 (M3)—Wet mitigation scenario where stabilisation of 550 ppm CO_2 equivalent (CO_2 stabilised at 500 ppm) is reached by 2100, 90th percentile rainfall and relative humidity surface for Australia (wet extreme), 50th percentile temperature surface. Mean global warming reaches ~2.0℃ in 2100.

Mitigation Scenario 4 (M4)—*Best estimate* (median) strong mitigation scenario where stabilisation of 450 ppm CO_2 equivalent (CO_2 stabilised at 420 ppm) is reached by 2100, 50th percentile rainfall and relative humidity surface for Australia, 50th percentile temperature surface. Mean global warming reaches ~1.5℃ in 2100.

Note: For each of the above scenarios global mean temperature is presented from a 1990 baseline. To convert to a pre-industrial baseline add 0.5℃

A global climate sensitivity of 3℃ has been applied to all scenarios. This is considered by the IPCC as the 'best estimate' climate sensitivity.

2 Health outcome models

2.1 Temperature-related mortality and hospitalisations

Mortality—methods and assumptions

The initial task is to characterise the relationship between daily temperature and deaths, for specified portions of the Australian population. Once the form of this relationship is known, it becomes possible to estimate how a future change in the annual distribution of daily temperatures, under climate change scenarios, will be reflected in a change in the pattern and total of temperature-related deaths. This estimation also takes account of changes in the size and age composition of the population, within each of the areal units for which the modelling is done.

Health data

De-identified unit record data for Australian deaths (all causes) from 1990 to 2005 were obtained from the Australian National Mortality Database (Australian Bureau of Statistics).[2] Deaths were analysed by the address of usual residence at time of death within the census geographical classification system called Statistical Divisions (SD). Ethical approval was obtained from the ANU human research ethics committee.

Population

Estimated resident population for each SD were obtained for each census year (1991, 1996, 2001 and 2006) and annual estimates were calculated by linear interpolation.[3–5]

Future population projections were obtained for the capital cities and rest-of-state areas for each State and Territory between 2004 and 2051.[6] We used the mid-range estimates (series B). Population estimates were not available at this disaggregated level beyond 2051, so population projections for the nation between 2052 and 2100 were used.[7] The national figures were adjusted based on the proportion of the national total each capital city and rest-of-state area was estimated to have (in each age-group) in the year 2051. We assumed these proportions stayed constant for the latter half of the century.

Climate

We used daily maximum temperatures and daily precipitation in the 24 hours to 9 am (mm) for all monitoring stations from the National Climate Centre of the Bureau of Meteorology Research Centre.[8] From these we calculated daily area-level climate estimates for each Statistical Division, adjusting for distance from each Census Collection District to a monitoring station.[9] This method gives a weighted average of station observations, based on the weather experienced by the majority of the people residing within a Statistical Division.

Modelling

Data

Daily mortality for 1990–2005, by (a) States and Territories, (b).capital cities versus rest-of-state, and (c) four age-groups: 45–54 years, 55–64 years, 65–74 years and 75+ years were used. The modelling accounted for season (djf, mam, jja, son).

Statistical model

We modelled the effects of daily temperature on death rate using Poisson regression. The population (exposure) variable used was ‘estimated resident population’ (ERP), interpolated between ABS census dates. We investigated the dependence of death rate on daily maximum temperature, allowing for variation in response over the factors listed above.

De-trending

To avoid confounding the temperature effects with seasonal and longer-term trends, we included terms in the models to adjust for these. The long-term trend was modelled through a natural spline curve with 2 degrees of freedom (df) per year (32df for the 16 years). Annual cycles were modelled through sine and cosine terms of the form $\sin(2\pi d/365)$ and $\sin(4\pi d/365)$, where ‘d’ is the day number, from 1 Jan=1 to 31 Dec=365. We found that frequencies higher than the second harmonic were not required. These cycles added 4df to the model.

Functional form
The functional form assumed for the response to maximum temperature was a ‘broken stick’: we assumed the death rate increased both above a certain threshold (high maximum temperature) and below a certain threshold (low maximum temperature). Exploratory modelling suggested that (log) risk increased approximately as the square of the temperature excursion above the upper threshold, and linearly with temperature below the lower threshold. The two thresholds at each location were estimated by maximisation of log-likelihood over a 1 °C grid, subject to the lower slope being negative and the upper slope being positive to achieve a ‘U’-shaped overall response.

Lag effects
Effects of the previous few days on each day’s deaths were captured through constrained distributed lag modelling over 10 days (lags 0 to 9). Rather than estimate a separate slope for each lag, these slopes are assumed to lie on a polynomial curve. Polynomials with three degrees of freedom were used, estimating three parameters for the effect of cold and three for heat (instead of 10 for each). The polynomials were constrained to be zero at lag 10, and to meet this constraint smoothly, by including only terms in X^2, X^3 and X^4, where X=10–lag for lag=0…9.

The overall effect of a particular day’s temperature is therefore assumed to act on that day and over the following nine days. The total effect on log death rate per degree is the sum of the parameters over all ten days, and this is the coefficient that is carried forward into the projections. If a positive increase in mortality is due in part to short-term mortality displacement (‘harvesting’), this will be seen as negative lagged effects which will offset the total. Therefore the coefficients used in the projections represent real increases in mortality, net of any displacement of up to nine days.

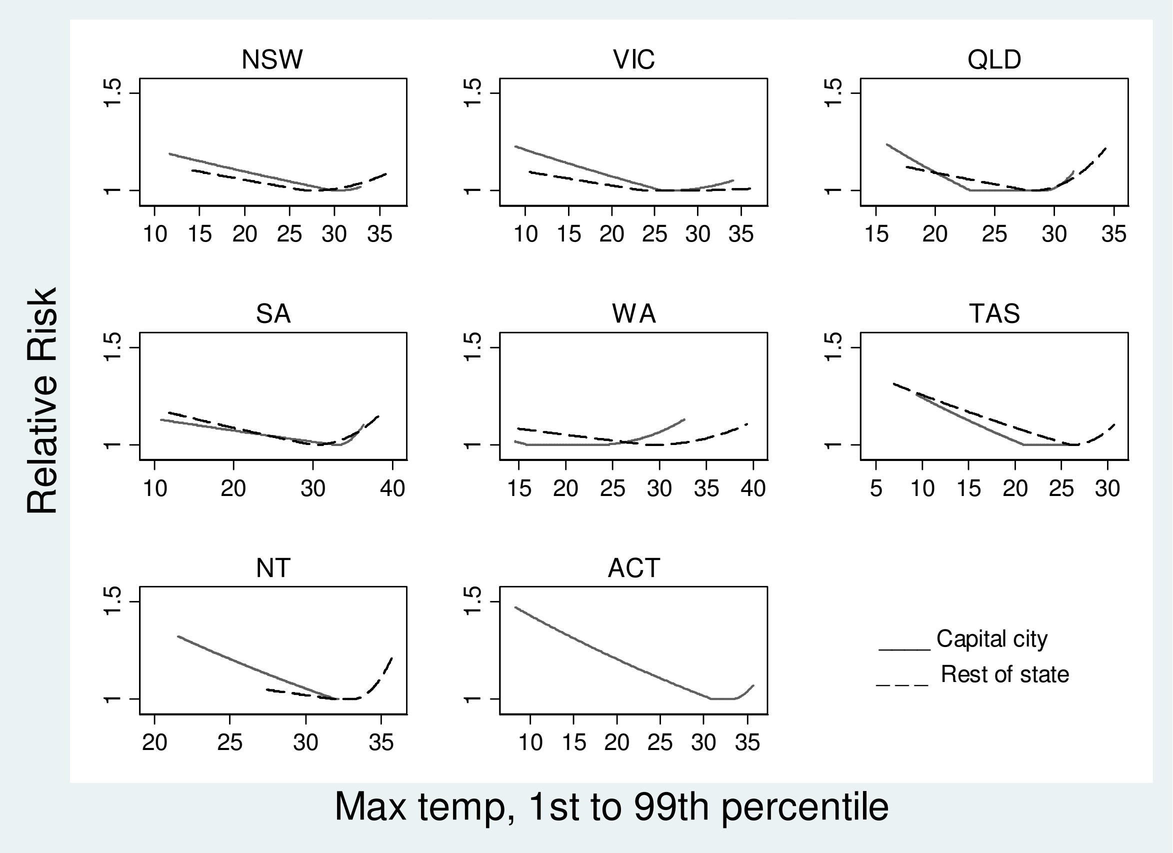
Results
The temperature thresholds (see ‘functional form’ above) and coefficients varied considerably by location, but not greatly by either age-group or season. Values were therefore estimated for each capital, and for the remainder of each State and of the Northern Territory. There was no consistent pattern of dependence of deaths on temperature in age groups 0–4 to 40–44, so zero effect was assumed for ages 0–44. Estimated coefficients were similar, and with no consistent pattern, over age groups 45–49 to 80+, so a common effect was assumed over ages 45+. Table 1 shows the coefficients and Figure 1 the implied functions.

The temperature variable we used was daily maximum temperature, Tmax. The measure of cold was: $C=\min(0, \mathrm{Tmax}-T_C)$; and of heat: $H=\max(0, \mathrm{Tmax}-T_H)$. The modelled log death rate increased by $\beta_c C/100 + \beta_h H^2/100$, which is zero between the two thresholds and increases either side of that range ($\beta_c<0$, $\beta_h>0$).

Table 1 **Coefficients for temperature-mortality relationships by capital city and rest of state**

	COLD		HEAT	
	Threshold T_C	Coeff, β_C	Threshold T_H	Coeff, β_H
Rest of NSW	30	–0.946	30	0.233
. Sydney	27	–0.786	27	0.110
Rest of VIC	26	–1.197	26	0.079
. Melbourne	24	–0.679	26	0.011
Rest of QLD	23	–3.020	29	1.362
. Brisbane	28	–1.111	28	0.497
Rest of SA	33	–0.552	33	0.894
. Adelaide	30	–0.848	30	0.204
Rest of WA	16	–1.295	23	0.132
. Perth	29	–0.575	29	0.094
Rest of TAS	21	–1.980	21	0.010
. Hobart	26	–1.429	26	0.452
Rest of NT	32	–2.683	40	0.000
. Darwin	32	–1.045	33	2.669
ACT	31	–1.702	33	0.975

Figure 1 **Mortality response functions for the eight States and Territories of Australia. The functions are log-linear below the low threshold and log-quadratic above the upper threshold. The Australian Capital Territory was not subdivided.**



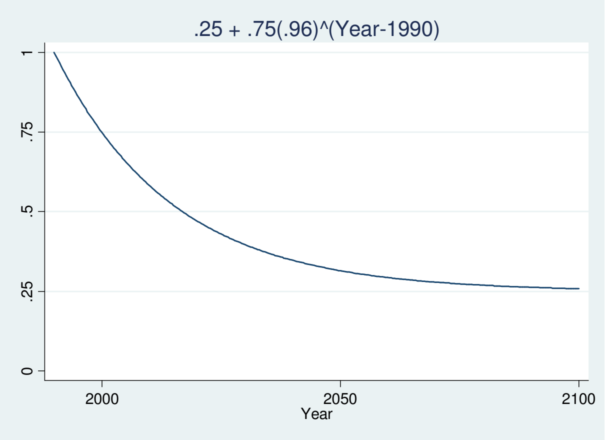
Projection

<u>Method</u>

The datasets described above were used to derive:

a) the temperature distribution in each State and Territory, for the capital city and rest-of-State in each season, rounded to the nearest degree Celsius;

b) the baseline *per capita* death rate, by State, capital/rest-of-state, age-group and season, excluding estimated heat-related deaths. These rates were calculated by applying the response functions to the actual temperatures to estimate by what factor the deaths would have been increased on each day, then dividing by these factors. This was done for eighteen 5-year age-groups, from 0–4 to 85+.



The Australian population is projected to age considerably over the coming century. For example, the age group 85+ represented about 1% of the population in 1995, but this is projected to rise to 6.5%. Over this time, the total population will increase by about 50%, yet applying the baseline death rates to the changing population structure results in projected total annual deaths rising six-fold, which is clearly inconsistent. In order to constrain the total death rate to rise only proportionally, we scaled down the age-specific deathrates over time, using one factor applied to all age-groups. Non-linear modelling provided the function graphed, which best maintains the overall per capita death rate approximately constant.

The baseline temperature distributions were then extended annually to 2100, applying each year's modelled scenario warming to the temperature distributions by State, capital/rest-of-state, and season. The *per capita* death rates in each age-group, adjusted downward by calendar year, were scaled by the ABS projected populations and by the relative death rate at each temperature, according to the modelled functions. The result was then averaged over the temperature distributions in each season. Finally, the projected deaths were summed over seasons, age-groups and capital/ rest-of-state to give annual State totals.

Assumptions

- The modelled response functions, while a reasonable representation of associations found in historical data, are simplifications. In particular, they assume that the relative risks estimated for a particular location apply throughout the calendar year and for all adult ages. This assumption could be relaxed to give a more complex and perhaps more realistic model, but at the cost of estimating more parameters from limited data and therefore estimating them less accurately. Our modelling captures the most important variations in relative risk.

- The model assumes, for any specified day, that the effects of heat or cold over the preceding 10-day period act multiplicatively on risk on that day. No attempt was made to allow for the cumulative stress of heatwaves or cold snaps. This is currently an active research area, and there is no internationally agreed index of how best to measure cumulative heat stress.

- The projection assumes that the response functions estimated from 1990–2005 records will continue to apply into the future. No allowance is made for local populations adapting to changing climatic conditions, whether physiologically, behaviourally or through use of technology. Although some degree of adaptation may occur, there is no data on its likely extent or the rate at which it might develop.

- The method for projecting age-specific death rates assumes an equal proportional decrease across all ages, as the population expands and ages from 1990 to 2100.

Hospitalisations—methods and assumptions

The same rational and approach were used for this part of the analysis as for the mortality analysis above.

Data

The available data consisted of eight years of daily emergency hospital admissions for Sydney, Melbourne and Brisbane, together with daily weather. The effects of daily maximum temperatures were explored, allowing for trend and cycles as described above for mortality. Model parameters estimated for Brisbane were assumed to apply to Queensland and the Northern Territory, those for Sydney were applied to New South Wales, the ACT, South Australia and Western Australia, and those for Melbourne were applied to Victoria and Tasmania.

Statistical model

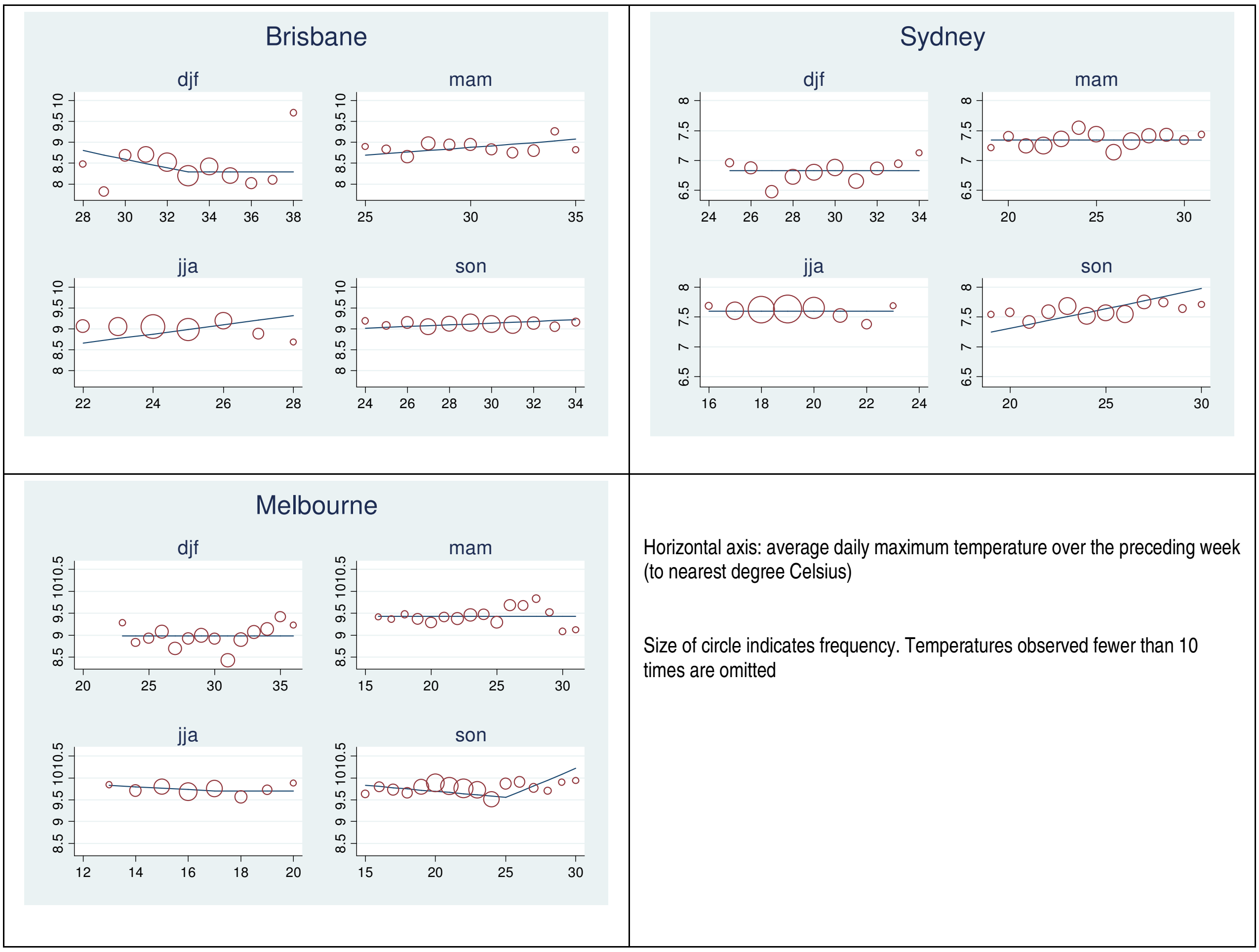
Poisson regression with population as exposure was used, with trend accounted for using 2df per year (16df) and annual cycles with 6df (cycles with periods of 1, ½ and ¼ year). Lag effects were modelled as above. Exploratory analyses suggested that most responses are linear, not quadratic, hence linear effects were assumed at each lag. A single break-point was assumed, with hospitalisations increasing both above and below this threshold. For numerical stability, the threshold was constrained to lie between the 10th and 90th percentiles of the temperature distribution within each season. Also, the slope above the threshold was constrained to be non-negative and the slope below to be non-positive. Within these constraints, the optimal threshold was chosen by maximum R^2 over a 1 °C grid.

Results
Total effects (summing over 10 lags) are tabulated in Table 2 and response functions illustrated in Figure 2. The measure of cold was: C=min(0, Tmax–T); and of heat: H=max(0, Tmax–T). The modelled log death rate increased by $\beta_c C/100 + \beta_h H/100$, which increases linearly either side of the single threshold T.

Table 2. Hospitalisations: response functions to daily maximum temperature

	Season	Breakpoint (°C)	β_c	β_h
Sydney	djf	21	–9.4588	0
	mam	-	0	0
	jja	16	–0.0996	0
	son	16	–1.9216	0.8737
Melbourne	djf	23	–0.3203	0
	mam	-	0	0
	jja	17	–0.3148	0
	son	25	–0.2830	1.3359
Brisbane	djf	33	–1.1976	0
	mam	23	–1.7299	0.4279
	jja	20	–4.4706	1.2312
	son	21	–0.4412	0.2220

Figure 2 **Response functions to daily maximum temperature by season, overlaid with seasonally adjusted rates per 10,000 population**



Horizontal axis: average daily maximum temperature over the preceding week (to nearest degree Celsius)

Size of circle indicates frequency. Temperatures observed fewer than 10 times are omitted

NB. As the modelling presented here for mortality and hospitalisations is temperature-based only, scenarios U3 and M3 have been omitted as their modelled temperatures are the same as for U2 and M2 respectively.

Results

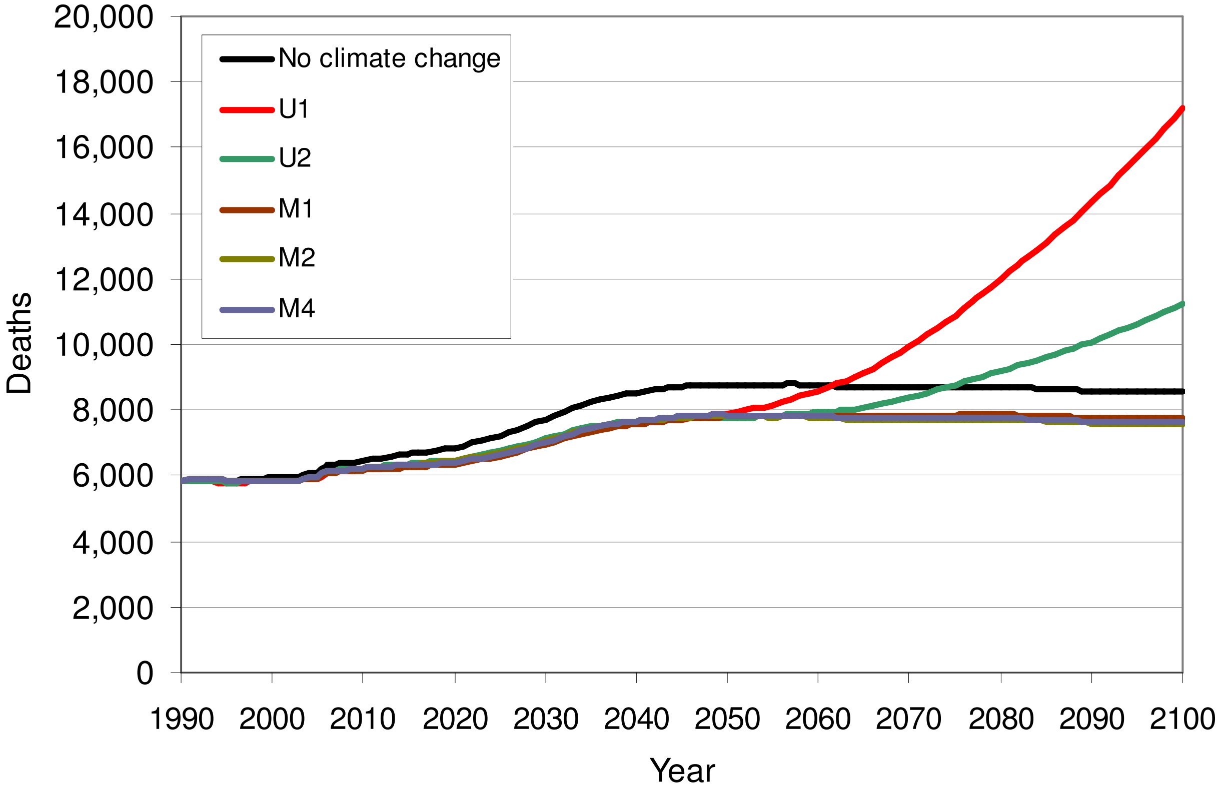
The results for temperature-related mortality and morbidity are highly variable, over place, time and climate change scenario, with climate change reducing temperature-related deaths and hospitalisations (due to fewer cold-deaths) in some parts of Australia, but increasing them in others (Tables 3 and 4). In relation to a scenario of no climate change (i.e. population changes only in relation to climate relationships at 1990 baseline), climate change is expected to reduce deaths in all states and territories except Queensland in the first half of the century (Table 3). The picture for the second half of the century is more mixed, with increases expected overall under scenarios of no mitigation (U1 and U2). Table 3 and Figure 3 show estimates for deaths in Australia for the coming century under the maximum change unmitigated scenario (U1) and the strong mitigation scenario (M4). With mitigation, deaths in the second half of the century will be considerably reduced.

Unmitigated climate change may modestly reduce temperature related deaths in Victoria, Tasmania, South Australia and NSW (due to reductions in the number of cold-related deaths), but markedly increase deaths in Queensland and the Northern Territory (with 10 times as many deaths by the end of the century compared with no climate change) and in Western Australia (twice as many deaths).

Table 3 Number of annual temperature-related deaths expected under scenarios U1 and M4 and percentage change relative to 1990 baseline, selected years. The scenario of 'No climate change' considers future deaths with population changes only.

State	Year	No climate change		U1		M4		Number of deaths at 1990 baseline
ACT	2020	255	61%	241	53%	241	53%	158
	2050	340	115%	284	80%	304	92%	
	2070	338	114%	261	65%	300	90%	
	2100	333	111%	262	66%	295	87%	
NSW	2020	2323	11%	2138	2%	2145	2%	2097
	2050	2824	35%	2196	5%	2417	15%	
	2070	2802	34%	1976	–6%	2372	13%	
	2100	2754	31%	2040	–3%	2334	11%	
NT	2020	60	11%	58	7%	58	7%	54
	2050	66	22%	117	117%	78	44%	
	2070	63	17%	281	420%	78	44%	
	2100	61	13%	768	1322%	76	41%	
Qld	2020	1153	78%	1062	64%	1062	64%	649
	2050	1784	175%	2162	233%	1680	159%	
	2070	1780	174%	4558	602%	1697	161%	
	2100	1747	169%	11322	1645%	1664	156%	
SA	2020	749	–1%	718	–5%	720	–5%	756
	2050	833	10%	740	–2%	774	2%	
	2070	824	9%	710	–6%	762	1%	
	2100	811	7%	740	–2%	750	–1%	
Tas	2020	357	1%	333	–5%	334	–5%	352
	2050	387	10%	310	–12%	340	–3%	
	2070	381	8%	259	–26%	332	–6%	
	2100	375	7%	211	–40%	327	–7%	
Vic	2020	1615	7%	1495	–1%	1499	0%	1505
	2050	2013	34%	1548	3%	1730	15%	
	2070	2000	33%	1272	–15%	1700	13%	
	2100	1966	31%	1012	–33%	1673	11%	
WA	2020	347	32%	347	32%	347	32%	262
	2050	525	100%	554	111%	528	102%	
	2070	524	100%	645	146%	528	102%	
	2100	515	97%	835	219%	519	98%	
Aust	2020	6859	18%	6392	10%	6406	10%	5833
	2050	8772	50%	7911	36%	7851	35%	
	2070	8712	49%	9962	71%	7769	33%	
	2100	8562	47%	17190	195%	7638	31%	

Figure 3 **Modelled temperature-related deaths for Australia as a whole over the coming century for the five temperature scenarios. 'No climate change' considers population changes only**

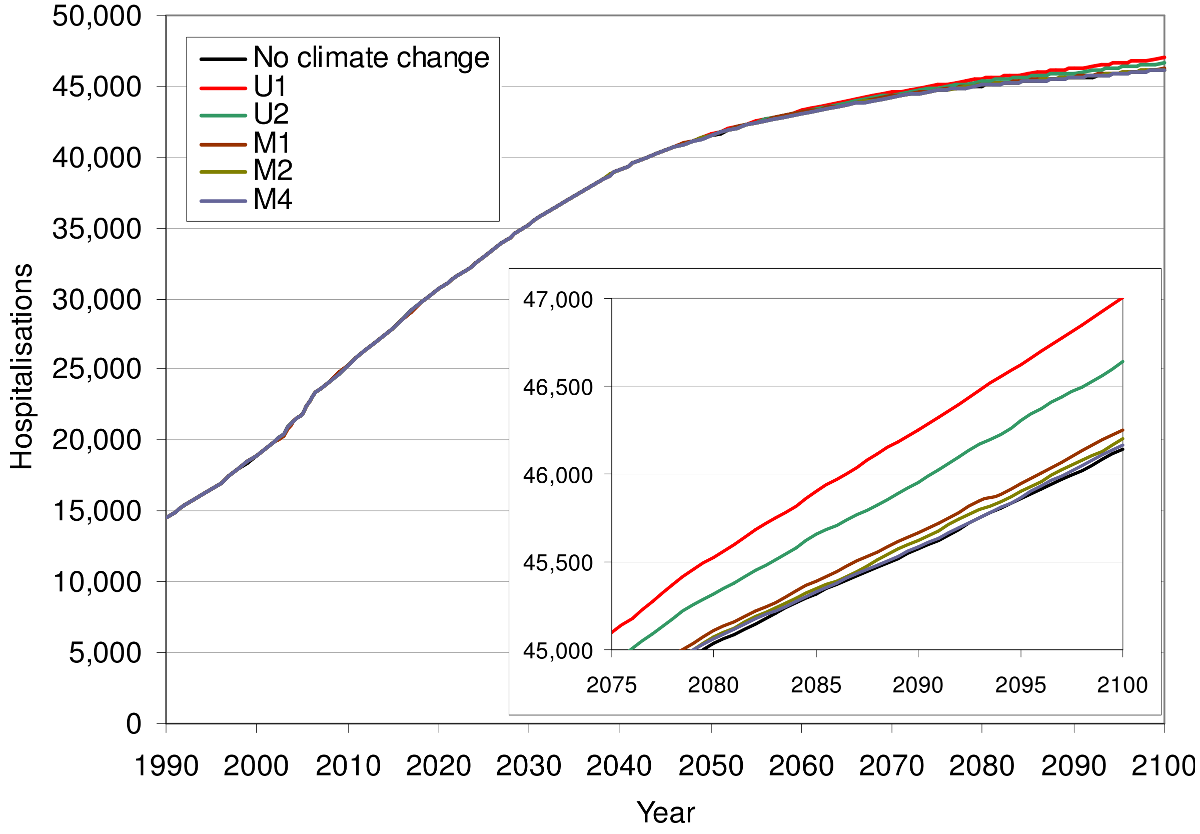


The expected pattern of temperature-related hospitalisations under climate change is somewhat different, with unmitigated climate change causing slight increases across the states and territories, with the exception of Tasmania which may experience a slight decrease (Table 4). Hospitalisations under the strong mitigation (M4) scenario are very closely aligned with numbers expected without climate change. Most of the impact of climate change will be delayed until the second half of the century (Figure 4).

Table 4 **Annual number of temperature-related hospitalisations expected under scenarios U1 and M4 and percentage change relative to 1990 baseline, selected years. The scenario of 'No climate change' considers future hospitalisations with population changes only.**

State	Year	No climate change		U1		M4		Number of hospitalis-ations at 1990 baseline
ACT	2020	387	130%	387	130%	387	130%	168
	2050	493	193%	494	194%	492	193%	
	2070	526	213%	526	213%	523	211%	
	2100	544	224%	555	230%	545	224%	
NSW	2020	8916	85%	8933	86%	8934	86%	4814
	2050	11472	138%	11575	140%	11525	139%	
	2070	12214	154%	12431	158%	12273	155%	
	2100	12753	165%	13161	173%	12816	166%	
NT	2020	243	212%	245	214%	245	214%	78
	2050	384	392%	389	399%	386	395%	
	2070	403	417%	413	429%	404	418%	
	2100	422	441%	438	462%	424	444%	
Qld	2020	6845	222%	6819	221%	6820	221%	2124
	2050	10645	401%	10569	398%	10588	398%	
	2070	11371	435%	11327	433%	11298	432%	
	2100	11862	458%	11932	462%	11794	455%	
SA	2020	2061	69%	2060	69%	2060	69%	1218
	2050	2271	86%	2279	87%	2276	87%	
	2070	2402	97%	2429	99%	2410	98%	
	2100	2509	106%	2561	110%	2517	107%	
Tas	2020	829	75%	827	74%	827	74%	475
	2050	854	80%	850	79%	850	79%	
	2070	908	91%	894	88%	895	88%	
	2100	943	99%	936	97%	938	97%	
Vic	2020	8545	90%	8536	90%	8539	90%	4500
	2050	11203	149%	11189	149%	11188	149%	
	2070	11936	165%	11948	166%	11908	165%	
	2100	12445	177%	12575	179%	12433	176%	
WA	2020	2843	144%	2853	145%	2852	145%	1166
	2050	4197	260%	4247	264%	4220	262%	
	2070	4476	284%	4571	292%	4500	286%	
	2100	4664	300%	4848	316%	4695	303%	
Aust	2020	30669	111%	30660	111%	30664	111%	14543
	2050	41519	185%	41592	186%	41525	186%	
	2070	44236	204%	44539	206%	44211	204%	
	2100	46142	217%	47006	223%	46162	217%	

Figure 4 **Number of temperature-related hospitalisations in Australia by year for each of the temperature scenarios. 'No climate change' considers population changes only. Inset is detail for 2075 to 2100**



Economic costs associated with mortality and hospitalisations

Hospital costs

In 2004/5 the average cost of a hospital stay was $3410, with an average length of stay in hospital of 3.7 days.[10] It is assumed, in the absence of hospitalisation data relating specifically to costs and length of stay for temperature-related admissions, that these averages apply here. Hospital costs are assumed to apply to all ages equally.

Lost workdays associated with hospitalisation

We assume that those aged over 65 who are hospitalised are not in the paid workforce or being cared for by someone in the paid workforce. We assume that those aged less than 65 years are either in the paid workforce or being cared for by someone in the paid workforce. Thus lost workdays due to illness were calculated only for the proportion of people hospitalised aged less than 65 years, or 63% of the total.

The minimum number of lost workdays was there fore estimated by multiplying the length of hospital stay (3.7 days) by the proportion of the number of working days in a year (234/365=0.64) by the proportion of patients assumed to be either in the paid workforce or being cared for by someone who is in paid employment (0.63). The minimum number of lost workdays is therefore estimated to be 1.5 days per admission.

Assuming that these averages apply to hospitalisations caused by heat-stress, the estimated numbers of hospitalisations can be converted directly.

Lost workdays due to years of economically active life lost (mortality and hospitalisation)

The economic cost of a death arises primarily from the lost productivity due to years of economically active life lost (YLL). This cost was estimated by assigning an average retirement age to those of each age-group currently in the workforce, based on typical workforce participation rates (Table 5).

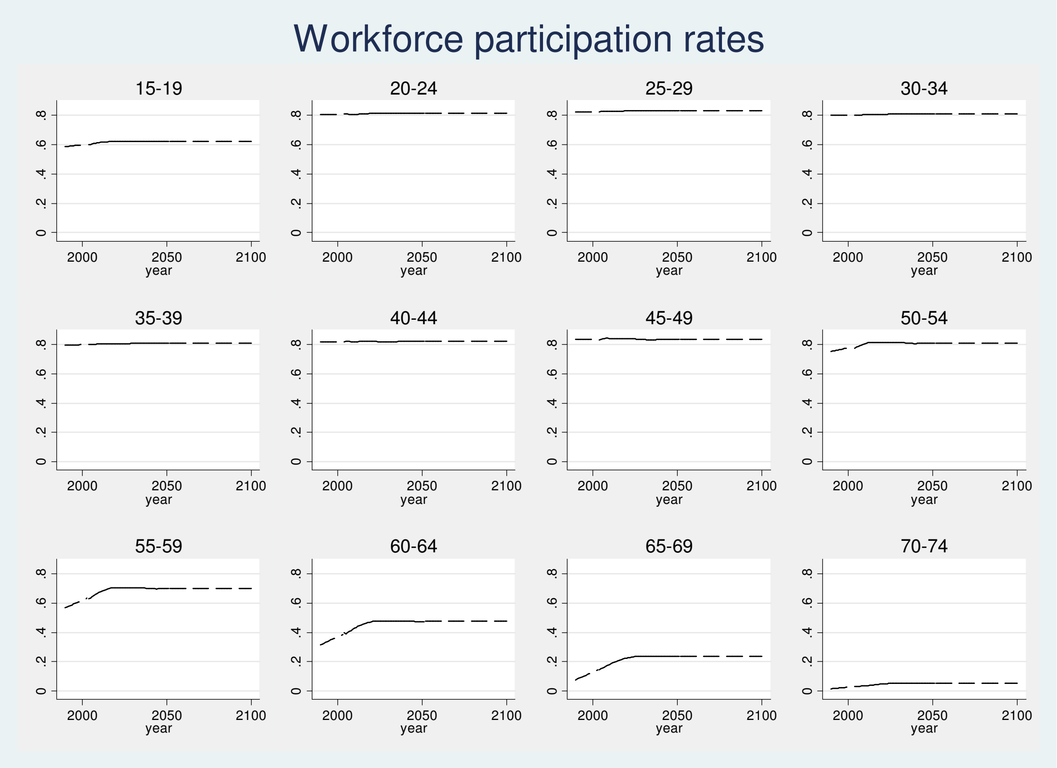
Table 5 **Workforce participation**

Age group	Median working age	Participation rate	Average retirement age	Working years lost
0–4	17	0	64	47
5–9	17	0	64	47
10–14	17	0	64	47
15–19	17	60%	64	47
20–24	22	80%	64	42
25–29	27	80%	64	37
30–34	32	80%	64	32
35–39	37	80%	64	27
40–44	42	80%	64	22
45–49	47	80%	64	17
50–54	52	80%	64	12
55–59	57	70%	64.5	7.5
60–64	62	50%	66	4
65–69	67	20%	72	5
70–74	72	10%	74.5	2.5

These estimates of working years lost were then converted to lost working days by multiplying by 234 working days per year, this being a reasonable national average allowing for public holidays. The workforce participation rates have changed historically, and are projected to change further. Figure 5 shows projected rates as received (REF: QLD Govt) for 2004 to 2051. These were extrapolated back to 1990 and forward to 2100 as shown in Figure Y (dashed lines). The overall formula for working days lost was therefore:

$$\text{dayslost} = \text{heatdeaths} \times \text{participation} \times \text{yearslost} \times 234$$

Figure 5 **Projected workforce participation by age-group. Solid lines: data provided by Garnaut Team (2004–2051); dashed lines: extrapolations**



The estimated number of lost workdays due to YLL for Australia under the different scenarios is shown in Table 6 (by state and territory, selected scenarios and selected years) and Figure 6 (Australia, all scenarios).

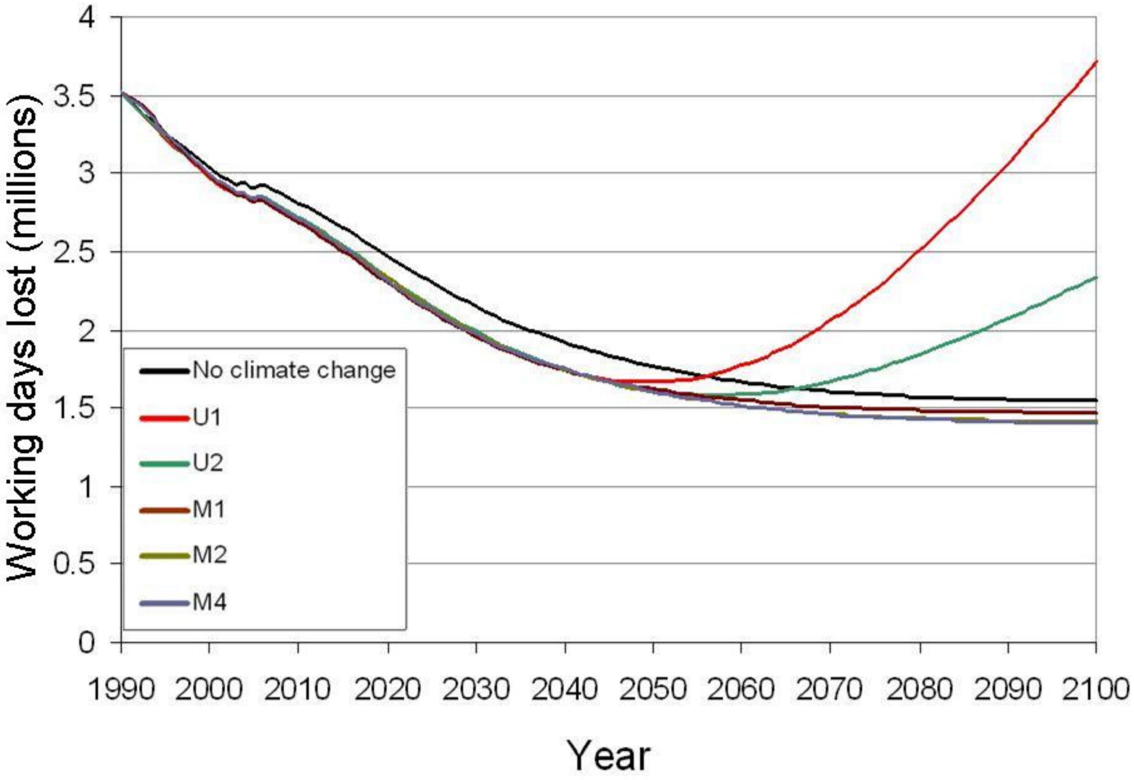
Overall for Australia, in U1 scenario small gains may be made in the first half of the century with moderate losses by the end of the century, but again the climate change impacts vary considerably between states and territories; Queensland, the Northern Territory and Western Australia will expect substantial loss in economic productivity due to impacts on active YLL. By the end of the century under the U1 scenario, Queensland will experience a loss of workdays about seven times that without climate change, the Northern Territory about eight times and Western Australia about double.

These calculations of lost productivity do not take into account likely reduced workplace productivity on a day-to-day basis from, for example, increased fatigue, that may occur as the climate warms. Industries most affected would be those that conduct their activities largely outdoors, such as the building sector, agriculture, and tourism.

Table 6 **Annual number of lost workdays due to temperature-related morbidity and mortality expected under scenarios U1 and M4 and percentage change relative to 1990 baseline, selected years. The scenario of 'No climate change' considers future hospitalisations with population changes only.**

State	Year	No climate change		U1		M4		Number of lost work days at 1990 baseline
ACT	2020	101,205	–35%	95,397	–39%	95,523	–39%	156,388
	2050	70,392	–55%	58,834	–62%	62,880	–60%	
	2070	63,904	–59%	49,834	–68%	56,639	–64%	
	2100	61,426	–61%	50,554	–68%	54,480	–65%	
NSW	2020	799,888	–33%	735,911	–39%	738,206	–38%	1,197,990
	2050	564,060	–53%	440,411	–63%	482,703	–60%	
	2070	512,228	–57%	369,951	–69%	433,686	–64%	
	2100	492,512	–59%	388,687	–68%	417,387	–65%	
NT	2020	87,004	–33%	79,264	–39%	79,667	–39%	129,548
	2050	68,066	–47%	87,356	–33%	67,544	–48%	
	2070	62,088	–52%	177,212	37%	62,906	–51%	
	2100	59,628	–54%	466,083	260%	60,317	–53%	
Qld	2020	449,277	11%	423,162	5%	422,864	5%	404,103
	2050	376,498	–7%	495,101	23%	373,434	–8%	
	2070	343,428	–15%	965,488	139%	346,587	–14%	
	2100	330,222	–18%	2,329,416	476%	332,700	–18%	
SA	2020	239,951	–44%	230,418	–46%	231,081	–46%	425,950
	2050	142,678	–67%	127,397	–70%	132,844	–69%	
	2070	128,891	–70%	112,363	–74%	119,466	–72%	
	2100	123,939	–71%	115,875	–73%	114,922	–73%	
Tas	2020	111,570	–44%	104,236	–48%	104,513	–48%	200,374
	2050	62,261	–69%	49,954	–75%	54,792	–73%	
	2070	56,105	–72%	38,456	–81%	48,926	–76%	
	2100	53,962	–73%	30,888	–85%	47,096	–76%	
Vic	2020	539,449	–35%	498,464	–40%	499,849	–39%	823,941
	2050	368,043	–55%	280,713	–66%	314,893	–62%	
	2070	333,860	–59%	209,461	–75%	282,296	–66%	
	2100	321,029	–61%	162,532	–80%	271,734	–67%	
WA	2020	139,541	–21%	141,245	–20%	141,116	–20%	177,234
	2050	111,896	–37%	122,991	–31%	115,038	–35%	
	2070	101,961	–42%	134,971	–24%	105,314	–41%	
	2100	98,022	–45%	175,502	–1%	101,196	–43%	
Aust	2020	2,467,886	–30%	2,308,096	–34%	2,312,818	–34%	3,515,528
	2050	1,763,895	–50%	1,662,758	–53%	1,604,126	–54%	
	2070	1,602,465	–54%	2,057,737	–41%	1,455,818	–59%	
	2100	1,540,740	–56%	3,719,538	6%	1,399,831	–60%	

Figure 6 **Estimated annual number of working days lost (millions) for Australia due to years of active life lost (YLL) that considers both mortality and hospitalisations**



Key messages

Exposure to prolonged ambient heat promotes various physiological changes, including cramping, heart attack and stroke. People most likely to be affected are those with chronic disease (e.g. cardiovascular disease, type 2 diabetes) and hence are older people as a group, due to their higher burden of chronic disease. The ability to cool by sweating also decreases with age as the threshold temperature at which sweating commences increases.[11]

Different temperature-mortality and temperature-heat relationships exist in different regions, currently, suggesting some level of adaptation at the population level. We have not yet been able to consider the role that adaptation (physiological, behavioural and technological) could have, over time, in reducing the impacts of heat on mortality and morbidity as the population becomes more used to increased ambient temperatures. On the other hand, nor have we factored in the likely increase over coming decades in the prevalence of obesity and its serious cardiovascular and metabolic consequences, which would act in the opposite direction, altering the patterns of underlying chronic disease so that more people—and more younger people, still in the workforce—would be at risk of heat-related illness and death. Further, the future age profile of the workforce has not been considered here but is likely to increase the costs of lost productivity above those presented here as older people remain in paid work for longer.

Data limitations
The data used to define the temperature relationships with hospitalisations were only from Sydney, Melbourne and Brisbane, and these relationships were applied to other cities with similar climates. Future assessments could define relationships for each city and other major population centres across the states and territories.

Prevention
Past heatwaves, such as occurred in Chicago in 1995 and Europe in 2003, have highlighted the vulnerability of elderly people who are socially isolated. In Chicago, other factors which increased the risk of death were having a known illness and not leaving home each day, while access to transport,

having friends or activities nearby and air-conditioning were protective factors.[12] Lack of mobility and a high level of dependency among the elderly have been highlighted as risk factors,[13–15] and poor housing quality (inadequate insulation)[13] and perceptions of the neighbourhood as unsafe (whether a householder feels safe to leave their home to find somewhere cooler, or in opening a window at night) have also at times increased the risk of dying. Housing design (multiple storey, high uninsulated thermal mass) and urban landscape (asphalt, high density, buildings that reduce airflow, and little 'green space'—all of which contribute to the 'heat island' effect that imparts higher and more sustained overnight temperatures in inner city environments than in the suburbs and beyond) have also been linked to deaths during heatwaves.[12,16]

A heat-wave warning system could provide notice to carers and family to be on particular alert. Improving housing quality and passive solar retrofitting could reduce heat-related deaths, while neighbourhood planning and service provision (including transport) are recommended for people without support, and to improve mobility and perceptions of safety.

2.2 Salmonellosis and other bacterial gastroenteritis

Methods and assumptions

Health data

Salmonella is a bacterial pathogen that causes gastroenteritis, with symptoms including vomiting, diarrhoea, abdominal cramps and fever. It can be transmitted through the consumption of contaminated food and directly between people.

We used notification data for salmonellosis[2] from the National Notifiable Diseases Surveillance System by state and year and nationally by month for the period 1991 to 2006.[17] For consistency with the hospitalisation data and to reflect recent patterns we used the period 1998–2005 to determine the 'baseline' (2001) average characteristics.

We used the temperature-notification relationships defined by D'Souza et al,[18] who estimated the effects on the monthly number of *Salmonella* notifications using mean temperature of the previous month. These estimates were calculated for Adelaide, Brisbane, Melbourne, Perth, and Sydney. To model climate impacts in the present study for Darwin, Canberra and Hobart—which were not included in the D'Souza analysis—we used the D'Souza estimates for cities most closely related in climate: Brisbane, Sydney and Melbourne respectively. The effect size estimate was around a 5% increase in notifications per degree increase in the mean temperature of the previous month (4.1% in Perth to 5.6% in Sydney) for all cities except Brisbane (and Darwin). Brisbane showed a 10% increase per degree. These capital city estimates were applied to the State- and Territory-wide data. Given that the relationship between temperature and *Salmonella* was strongest in Brisbane (the warmest city), it is expected that using this estimate for Darwin and the rest of the Northern Territory will under-estimate the effects of temperature on *Salmonella* in that region.

Population

Notifications of *Salmonella* vary by region. Population projections for each State and Territory were supplied by the Australian Bureau of Statistics (ABS) for 5-year age groups to 2051 From 2052 to 2100 the ABS provides whole-of-country population projections only and we used the state-proportion of the national total at 2051 and interpolated annual State population totals from that date to 2100 as described above. As a consequence, all States show a slight increase in population after 2051, even in the few cases where there were declines predicted in the first half of the century. Given the implausibility of estimating with any great accuracy the likely drivers of state-wide population change several decades from now (e.g. changing industries, perhaps due to climate change), we consider this method to be as good as any other available. The effect of this method may be to underestimate salmonellosis rates in the latter half of the century. For example, the population of the Northern Territory (with the highest rates of notifications) is expected to experience intense growth to 2050, but

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[2] Data used here does not include *S. tyhphi* (overseas acquired)

the application of national growth estimates from 2051 to 2100 means that the trajectory will instead be much less steep, thus with fewer predicted cases than might otherwise be expected.

Climate

Annual average temperatures for the period 1961–1990 were obtained from the OzClim model (jointly developed by International Global Change Institute (IGCI), University of Waikato and CSIRO Atmospheric Research).[19] These data are based on 25 km square grids which we averaged across the Statistical Divisions. The region-specific temperature change values for each SD from the CSIRO models were added to the baseline temperatures.[20] We applied the D'Souza[18] estimates to annual average baseline rates according to the annual average temperatures for each capital city derived from the CSIRO scenarios for each State and Territory for annual mean temperature changes to 2100. We used capital city temperature estimates rather than a state average as these best reflect the conditions where a majority of people are living.

Modelling

Baseline rates

We assumed that the distribution of notifications by age in the national data was consistent for all States and Territories. Age group estimates were derived by multiplying the proportion of notifications for each age group by the mean annual number of notifications for each State and Territory. Thirty-five per cent of notifications were among 0–4 year olds, with four times as many cases as among 5–9 year olds (around 8%), declining to 0.9% for people aged over 85 years. Notified rates are usually much higher in 0–4 year olds because vomiting and diarrhoea can be particularly alarming among very young children, and concerned parents seek medical help more often.

We aggregated ages into 0–14 (contributing approximately 48.8% of *Salmonella* cases), 15–64 (43.8%) and 65+ years (7.4%) and assumed these relative contributions remained constant into the future.

Baseline costs

Hall and Kirk (2005) estimate there are 5.4 million cases of food-borne gastroenteritis each year in Australia, which is about one third of the average 17.2 million total gastroenteritis cases per year (Hall, pers comm.). Only a small part of all gastroenteritis is caused by infection with *Salmonella* bacteria. There were approximately 7500 notified cases of salmonellosis at the baseline (1998–2005 annual average). As *Salmonella* infection is estimated to be under-reported by a factor of 7 (Hall, forthcoming) the annual number of likely salmonellosis cases is approximately 52500, the contribution that *Salmonella* makes to the total burden of gastroenteritis in Australia is approximately 0.3% of the 17.2 million annual gastroenteritis cases. The average estimated market costs and lost work days for *Salmonella* were derived from Abelson et al. (2006) from their analysis of food-borne gastroenteritis costs for 2002 [21] (Table 7).

Table 7 **Annual estimated cost of health care, surveillance and control, and the number of work days lost due illness and caring**

		Estimates from Abelson et. al (all foodborne illness)	**Estimates per case of foodborne gastroenteritis**[1]
Health service costs[1]	Hospitalisation	$25.2 million	$4.67
	Emergency Department	$53.2 million	$9.85
	GP visit	$86.4 million	$16.00
	Laboratory costs	$8.7 million	$1.61
	Pharmacy costs	$26.3 million	$4.87
	Total	**$199.8 million**	**$37.00**
Cost of surveillance and control[2]	Laboratory testing, surveillance, maintaining OzFoodNet, administration and enforcement of regulations	$39.4 million	$7.30
Total		**$239.2 million**	**$44.30**
Productivity (lost work days due to illness and caring)[1]	Work days lost	2.1 million days	0.4 days

[1]Per case estimate calculated by dividing the total cost / number of lost workdays by 5.4 million, the annual estimated total number of foodborne cases of gastroenteritis.

If the estimate for the proportion of all gastroenteritis cases that is foodborne (one third) is applied to *Salmonella*, then the cost of surveillance and control would only apply to the that proportion *Salmonella* cases that are foodborne, or $2.43 per case ($7.30/3).

The per case estimate of the cost of health services and surveillance and control for Salmonella is therefore approximately

$$\$37.00 + (\$2.43) = \underline{\$39.43}$$

Of the total, 94% is attributable to health sector costs and 6% to the cost of surveillance and control.

As only approximately 1 in 7 cases is notified, the estimate for the health costs per *Salmonella* notification is $259.00 and $17.01 for surveillance.

Greater economic impact is caused by days of work lost from illness or caring. The estimate for the number of lost workdays is 0.4 days per case (assuming the mode of transmission of *Salmonella* has no bearing on the time taken off work). The number of lost workdays per *Salmonella* notification is thus estimated to be 2.8 days when under-reporting is considered. These estimates are applied across all ages as the foundation of the estimate, Abelson et al, made their estimates on a per case basis rather than per case in the paid workforce.

Projections of future Salmonella notifications

These were modelled in three stages: first, changes in notifications due to demographic change only (assumes no climate change); second, changes in notifications due to climate change only (assumes no demographic change); and third, changes in notifications due to both demographic and climate change (the 'full' model):

1. Notifications due to demographic change

We used the 2001 Census estimates to calculate a baseline notification rate for each State and Territory. To account for the contributions of future demographic changes, we estimated the annual number of notifications based on current rates and projected population changes to 2100 in each of the three age groups.

2. Notifications due to climate change

The estimates for the relationship between temperature and *Salmonella* notifications from D'Souza et al.[18] were applied to the modelled annual temperatures and baseline notification rates for each State and Territory by fitting a 2nd order polynomial (R^2=1) to determine the new rates in each age group at a given temperature.

3.*Salmonella* notifications due to both demographic and climate change

We estimated all notifications for *Salmonella* to 2100, accounting for likely changes to notifications due to demographic and climate change by applying the modelled rates in each age group to the projected population. The results for each age group were then summed to provide whole-of-population estimates.

Climate change and other causes of gastroenteritis

Climate change is likely to affect several other important causes of gastroenteritis in similar ways as *Salmonella*. Table 8 shows the average number of notifications for all the nationally notifiable causes of gastroenteritis in Australia (1999–2005),[17] their relative contribution to the total number of notified causes of gastroenteritis, and the percentage increase in cases in summer (December, January and February) relative to winter (June, July, August). Note that Table 8 does not include cases caused by viruses and reflects significant under-reporting of gastroenteritis (average of less than 25,000 of the estimated 17.2 million annual cases). Notified cases of Salmonella account for approximately 30% of all notified gastroenteritis.

Table 8 Notified pathogenic causes of gastroenteritis in Australia

Diagnosis	Annual average number of notification (1998–2005)	Relative contribution (%)	Summer excess (%)
Campylobacteriosis	14624	58.6	12.3
Salmonellosis[1]	7526	30.2	104.8
Cryptosporidiosis	2204	8.8	187.4
Shigellosis	546	2.2	30.3
STEC/VTEC[2]	54		77.5
Total	24950[3] 22750[4]		39.7[3] 33.9[4]

[1]Does not include *S. typhi* (overseas acquired)
[2]Shigatoxogenic/Verotoxin producing *Escherichia coli*. Notification data commences 1999.
[3]Including cryptosporidiosis. Notification data commences 2001.
[4]Not including cryptosporidiosis (see below).

A number of other enteric pathogens also considered important for gastroenteritis in Australia: *Clostridium perfringens*, *Vibrio parahaemolyticus*, *Aeromonas* spp., Giardia, norovirus and rotavirus. The first three of these are bacteria, and cases of gastroenteritis caused by these and other bacteria have been shown to peak in summer or have a positive relationship with ambient temperature.[22–26] Transmission of norovirus and rotavirus, on the other hand, tends to peak in winter.[27,28] This is due to facilitated transmission from close indoor association rather than having a direct (inverse) relationship with ambient temperature. Patterns of seasonal peaks in Giardia appear less consistent.[29,30]. Both cryptosporidiosis and giardiasis are waterborne diseases where parasitic oocysts are washed into the water supply from (for example) cattle farms. The spring and summer excess for cryptosporidiosis notifications may be largely due to recreational factors (i.e. more outdoor activity)[31] and rainfall run-off[30,32] rather than ambient temperature (although reduced freezing may facilitate overwintering of oocysts).[33]

It is difficult to estimate the precise contribution of each pathogen to the total burden of gastroenteritis, given the high and variable rates of under-reporting and the absence of available national data for all causes, and the geographic variability in dominant pathogens responsible. It is estimated for Australia as a whole, however, that bacteria account for 36% of all notified gastroenteritis cases, viruses for 49% and parasites (cryptosporidium and giardia) for 15%.[34]

Methods

There is consistent evidence that gastrointestinal infection with bacterial pathogens is positively associated with ambient temperature, as warmer temperatures enable more rapid replication.[22,35,36]

Not all of these bacterial pathogens will have the same relationship with ambient temperature as has been established for *Salmonella*. For example, a Canadian study has observed temperature effects on rates of notifications of *Campylobacter* and *Escherichia coli* to be approximately twice and four-times as great respectively as for *Salmonella*.[35]

If we discount notifications caused by cryptosporidiosis (Table 8 above), then the summer excess for all notified (bacterial) gastroenteritis causes is approximately 32% the size of the summer excess for salmonellosis (calculated by 33.9 (total average excess) / 104.8 (salmonellosis excess)). In order to calculate an estimate of the impact of climate change on the burden of bacterial gastroenteritis in Australia, we assumed that cases of gastroenteritis caused by bacteria have, on average, a relationship with temperature that is around 32% the effect size of *Salmonella*, based on the average summer excess for all notified causes. This relationship was applied to the baseline estimate of 6.1 million cases (36% of 17.2 million, assumes the proportion of notified gastroenteritis of bacterial origin applies to the proportion of total cases of gastroenteritis).

To estimate health and safety costs and the number of lost workdays due to climate change, we applied the health costs and workday estimates described above at the national level.

To estimate the total future gastroenteritis burden on Australia (bacterial, viral and parasitic), starting at the baseline annual estimate of 17.2 million cases we modelled increases expected due to population change alone, and then added the calculated contributions made by increases to bacterial cases. The total economic and productivity costs were then estimated by applying the per case estimates above.

NB. As the modelling for *Salmonella* and bacterial gastroenteritis is temperature-based only, scenarios U3 and M3 have been omitted as their modelled temperatures are the same as for U2 and M2 respectively.

Main findings

Salmonella

The expected number of new *Salmonella* notifications to result from climate change for selected years in each State and Territory are presented in Table 9. Associated costs of healthcare and surveillance are shown in Table 10, and the number of lost workdays in Table 11. Note that these estimates are based on modelled notifications only, and due to under-reporting may underestimate the impact of climate change by a factor of seven, i.e. the actual number of cases and associated costs are likely to be seven times higher. Figure 7 shows the annual number of new notifications due to climate change expected for Australia.

Table 9 Estimated annual number of new notifications of salmonellosis due to climate change. All temperature scenarios, selected years. NB. The actual number of cases may be approximately seven times higher, due to under-reporting.

State	Year	U1	U2	M1	M2	M4
ACT	2020	3	2	3	3	3
	2050	13	11	11	9	8
	2070	25	20	13	11	9
	2100	41	33	15	12	9
NSW	2020	57	46	67	54	65
	2050	293	234	242	194	171
	2070	566	449	301	241	194
	2100	930	732	343	274	200
NT	2020	4	3	4	3	4
	2050	23	18	19	15	13
	2070	46	36	23	19	15
	2100	78	61	27	22	16
Qld	2020	63	51	73	60	72
	2050	393	312	322	257	225
	2070	788	618	405	322	257
	2100	1,342	1,038	463	368	265
SA	2020	9	7	11	8	10
	2050	40	31	34	26	23
	2070	77	58	42	32	26
	2100	126	94	47	36	26
Tas	2020	2	2	3	2	3
	2050	9	7	8	6	5
	2070	17	14	9	8	6
	2100	28	22	11	9	6
Vic	2020	33	27	38	31	38
	2050	168	136	139	113	99
	2070	322	259	173	140	113
	2100	523	418	197	159	116
WA	2020	12	10	14	12	14
	2050	70	57	58	47	41
	2070	134	108	72	58	47
	2100	216	173	82	66	49
Aust	2020	184	149	214	173	209
	2050	1,009	807	833	667	586
	2070	1,976	1,564	1,038	830	667
	2100	3,285	2,572	1,185	946	687

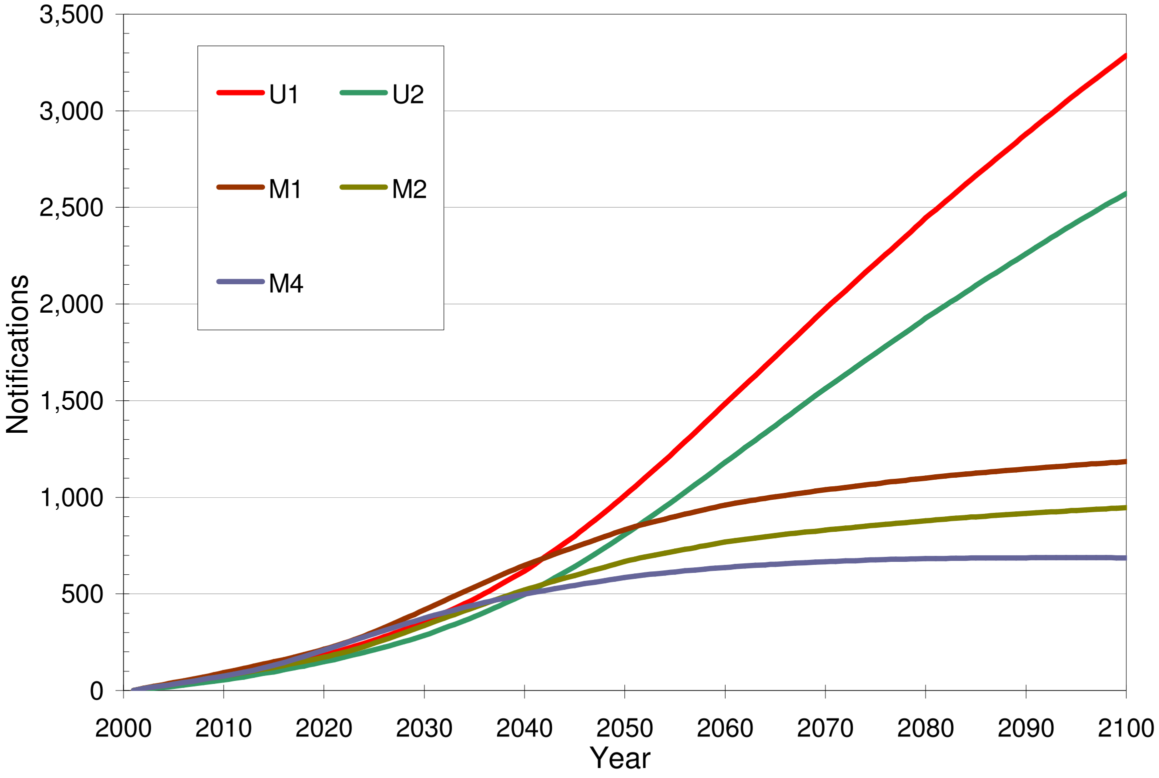
Table 10 **Estimated costs of healthcare and surveillance associated with notifications of salmonellosis due to climate change. All temperature scenarios, selected years. Costs are in AUD and based on estimates from 2005. NB. Costs are based on notifications rather than cases, and may underestimate the economic impact by a factor of seven.**

State	Year	U1	U2	M1	M2	M4
ACT	2020	724	598	843	696	842
	2050	3,592	2,939	2,971	2,436	2,140
	2070	6,923	5,623	3,682	3,015	2,426
	2100	11,361	9,154	4,193	3,430	2,500
NSW	2020	15,847	12,825	18,448	14,912	18,037
	2050	80,820	64,701	66,857	53,619	47,093
	2070	156,279	124,050	83,056	66,494	53,505
	2100	256,792	202,029	94,623	75,675	55,163
NT	2020	977	800	1,137	933	1,128
	2050	6,327	5,089	5,192	4,194	3,670
	2070	12,677	10,058	6,486	5,223	4,171
	2100	21,600	16,910	7,403	5,951	4,289
Qld	2020	17,405	14,134	20,281	16,425	19,876
	2050	108,374	86,204	88,979	70,998	62,131
	2070	217,629	170,677	111,736	88,881	71,027
	2100	370,284	286,442	127,804	101,481	73,202
SA	2020	2,581	1,990	3,001	2,313	2,791
	2050	11,170	8,507	9,268	7,073	6,224
	2070	21,312	16,094	11,459	8,730	7,047
	2100	34,659	25,941	13,048	9,930	7,273
Tas	2020	637	518	741	603	728
	2050	2,539	2,048	2,108	1,703	1,499
	2070	4,799	3,849	2,597	2,095	1,692
	2100	7,745	6,175	2,955	2,382	1,747
Vic	2020	9,111	7,447	10,596	8,662	10,471
	2050	46,388	37,584	38,453	31,211	27,444
	2070	88,853	71,511	47,701	38,661	31,176
	2100	144,480	115,467	54,288	43,963	32,150
WA	2020	3,387	2,758	3,953	3,219	3,903
	2050	19,283	15,637	15,997	12,986	11,416
	2070	36,898	29,762	19,886	16,127	13,003
	2100	59,695	47,864	22,622	18,334	13,408
Aust	2020	50,669	41,070	59,001	47,763	57,777
	2050	278,492	222,709	229,826	184,221	161,616
	2070	545,370	431,623	286,603	229,225	184,048
	2100	906,616	709,983	326,937	261,146	189,731

Table 11 **Estimated number of lost work days associated with salmonella notifications due to climate change. All temperature scenarios, selected years. NB. Number of work days lost is based on notifications rather than cases, and may be underestimated by a factor of seven**

State	Year	U1	U2	M1	M2	M4
ACT	2020	7	6	9	7	9
	2050	36	30	30	25	22
	2070	70	57	37	31	25
	2100	115	93	43	35	25
NSW	2020	161	130	187	151	183
	2050	820	656	678	544	478
	2070	1,585	1,258	843	675	543
	2100	2,605	2,049	960	768	560
NT	2020	10	8	12	9	11
	2050	64	52	53	43	37
	2070	129	102	66	53	42
	2100	219	172	75	60	44
Qld	2020	177	143	206	167	202
	2050	1,099	875	903	720	630
	2070	2,208	1,731	1,134	902	721
	2100	3,756	2,906	1,297	1,029	743
SA	2020	26	20	30	23	28
	2050	113	86	94	72	63
	2070	216	163	116	89	71
	2100	352	263	132	101	74
Tas	2020	6	5	8	6	7
	2050	26	21	21	17	15
	2070	49	39	26	21	17
	2100	79	63	30	24	18
Vic	2020	92	76	107	88	106
	2050	471	381	390	317	278
	2070	901	725	484	392	316
	2100	1,466	1,171	551	446	326
WA	2020	34	28	40	33	40
	2050	196	159	162	132	116
	2070	374	302	202	164	132
	2100	606	486	229	186	136
Aust	2020	514	417	599	485	586
	2050	2,825	2,259	2,331	1,869	1,640
	2070	5,533	4,379	2,907	2,325	1,867
	2100	9,197	7,202	3,317	2,649	1,925

Figure 7 **Expected annual number of salmonellosis notifications in Australia due to climate change for each of the five temperature scenarios. NB. The actual number of cases is likely to be approximately seven times higher due to under-reporting.**



All bacterial gastroenteritis

Table 12 shows the estimated number of new cases of bacterial gastroenteritis by State and Territory for selected years under the five different temperature scenarios. Tables 13 and 14 show the associated costs of health care and surveillance and the expected number of lost workdays. Note that these estimates include cases of salmonellosis. Figure 8 illustrates the expected annual numbers of cases of bacterial gastroenteritis due to climate change in Australia to 2100.

Table 12 **Estimated annual number of new cases of bacterial gastroenteritis due to climate change. All temperature scenarios, selected years**

State	Year	U1	U2	M1	M2	M4
ACT	2020	956	792	1,110	920	1,109
	2050	4,452	3,714	3,751	3,124	2,768
	2070	7,876	6,620	4,572	3,814	3,120
	2100	11,709	9,933	5,159	4,307	3,219
NSW	2020	20,706	16,804	24,046	19,522	23,541
	2050	99,126	81,084	83,535	68,211	60,433
	2070	175,617	144,884	102,062	83,471	68,292
	2100	260,845	217,426	115,188	94,298	70,497
NT	2020	1,144	942	1,328	1,094	1,318
	2050	6,586	5,490	5,579	4,638	4,118
	2070	11,317	9,571	6,767	5,639	4,635
	2100	16,177	13,914	7,594	6,339	4,773
Qld	2020	22,083	17,968	25,630	20,864	25,141
	2050	123,159	101,425	104,238	85,604	75,982
	2070	214,056	178,781	127,367	104,863	86,106
	2100	308,461	262,014	143,371	118,226	88,881
SA	2020	3,434	2,648	3,989	3,077	3,712
	2050	14,242	11,063	11,980	9,290	8,222
	2070	25,408	19,893	14,628	11,360	9,276
	2100	38,203	30,200	16,541	12,858	9,584
Tas	2020	837	680	973	791	954
	2050	3,237	2,643	2,718	2,217	1,961
	2070	5,805	4,764	3,316	2,708	2,209
	2100	8,810	7,274	3,754	3,067	2,282
Vic	2020	12,130	9,926	14,091	11,535	13,916
	2050	58,993	48,561	49,619	40,792	36,110
	2070	105,543	87,430	60,755	50,005	40,845
	2100	158,582	132,378	68,650	56,544	42,168
WA	2020	4,573	3,743	5,313	4,351	5,250
	2050	24,804	20,412	20,848	17,136	15,164
	2070	44,651	36,947	25,606	21,069	17,198
	2100	67,398	56,142	28,942	23,828	17,752
Aust	2020	65,863	53,503	76,480	62,153	74,941
	2050	334,598	274,391	282,268	231,012	204,759
	2070	590,272	488,890	345,072	282,929	231,681
	2100	870,184	729,282	389,198	319,467	239,156

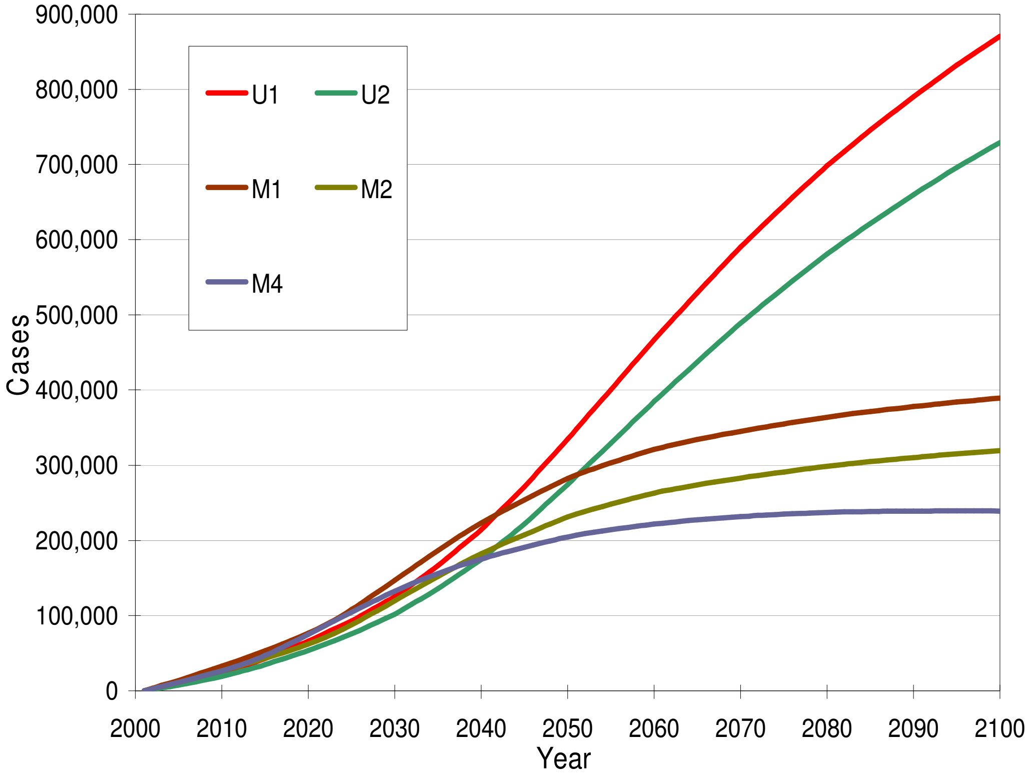
Table 13 Estimated costs of healthcare and surveillance associated with cases of bacterial gastroenteritis due to climate change. All temperature scenarios, selected years. Costs are in AUD and based on estimates from 2005

State	Year	U1	U2	M1	M2	M4
ACT	2020	263,835	218,568	306,411	253,926	306,211
	2050	1,228,751	1,025,089	1,035,268	862,344	764,001
	2070	2,173,808	1,827,295	1,261,931	1,052,619	861,177
	2100	3,231,696	2,741,516	1,423,804	1,188,668	888,606
NSW	2020	5,715,140	4,638,093	6,637,010	5,388,221	6,497,620
	2050	27,359,893	22,379,908	23,056,631	18,826,971	16,680,185
	2070	48,472,039	39,989,328	28,170,169	23,038,821	18,849,290
	2100	71,995,845	60,011,692	31,793,092	26,027,098	19,457,876
NT	2020	315,777	260,026	366,420	301,862	363,647
	2050	1,817,675	1,515,321	1,539,921	1,280,000	1,136,730
	2070	3,123,602	2,641,556	1,867,677	1,556,460	1,279,347
	2100	4,464,911	3,840,481	2,095,980	1,749,535	1,317,321
Qld	2020	6,095,263	4,959,362	7,074,015	5,758,791	6,939,214
	2050	33,992,998	27,994,212	28,770,832	23,627,532	20,971,920
	2070	59,081,714	49,345,266	35,154,598	28,943,354	23,766,189
	2100	85,138,332	72,318,545	39,571,912	32,631,616	24,532,151
SA	2020	947,830	730,743	1,101,139	849,226	1,024,629
	2050	3,931,057	3,053,423	3,306,575	2,564,117	2,269,384
	2070	7,012,746	5,490,633	4,037,384	3,135,468	2,560,222
	2100	10,544,320	8,335,611	4,565,598	3,548,907	2,645,181
Tas	2020	231,017	187,778	268,470	218,275	263,439
	2050	893,313	729,522	750,206	612,040	541,380
	2070	1,602,194	1,314,939	915,249	747,377	609,599
	2100	2,431,659	2,007,767	1,036,043	846,494	629,898
Vic	2020	3,347,930	2,739,638	3,889,373	3,183,661	3,840,863
	2050	16,282,672	13,403,323	13,695,292	11,258,991	9,966,638
	2070	29,130,869	24,131,629	16,768,862	13,801,978	11,273,724
	2100	43,770,149	36,537,564	18,947,977	15,606,791	11,638,692
WA	2020	1,262,106	1,033,204	1,466,514	1,200,792	1,448,926
	2050	6,846,151	5,633,875	5,754,202	4,729,716	4,185,379
	2070	12,324,030	10,197,844	7,067,446	5,815,145	4,746,790
	2100	18,602,503	15,495,830	7,988,149	6,576,863	4,899,731
Aust	2020	18,178,898	14,767,412	21,109,352	17,154,754	20,684,550
	2050	92,352,511	75,734,674	77,908,928	63,761,710	56,515,617
	2070	162,921,003	134,938,490	95,243,316	78,091,222	63,946,338
	2100	240,179,413	201,289,005	107,422,555	88,175,973	66,009,457

Table 14 **Estimated number of lost work days associated with cases of bacterial gastroenteritis due to climate change. All temperature scenarios, selected years**

State	Year	U1	U2	M1	M2	M4
ACT	2020	2,676	2,217	3,108	2,576	3,106
	2050	12,465	10,399	10,502	8,748	7,750
	2070	22,052	18,537	12,802	10,678	8,736
	2100	32,784	27,811	14,444	12,059	9,015
NSW	2020	57,978	47,051	67,330	54,661	65,915
	2050	277,554	227,034	233,899	190,991	169,213
	2070	491,728	405,674	285,774	233,719	191,218
	2100	730,366	608,792	322,527	264,033	197,392
NT	2020	3,203	2,638	3,717	3,062	3,689
	2050	18,440	15,372	15,622	12,985	11,532
	2070	31,688	26,797	18,947	15,790	12,978
	2100	45,295	38,960	21,263	17,748	13,364
Qld	2020	61,834	50,311	71,763	58,420	70,395
	2050	344,844	283,989	291,867	239,691	212,751
	2070	599,358	500,586	356,628	293,618	241,098
	2100	863,691	733,640	401,440	331,033	248,868
SA	2020	9,615	7,413	11,171	8,615	10,394
	2050	39,879	30,976	33,544	26,012	23,022
	2070	71,141	55,700	40,957	31,808	25,972
	2100	106,967	84,561	46,316	36,002	26,834
Tas	2020	2,344	1,905	2,724	2,214	2,672
	2050	9,062	7,401	7,611	6,209	5,492
	2070	16,254	13,339	9,285	7,582	6,184
	2100	24,668	20,368	10,510	8,587	6,390
Vic	2020	33,963	27,792	39,456	32,297	38,964
	2050	165,181	135,971	138,933	114,218	101,107
	2070	295,520	244,805	170,113	140,015	114,367
	2100	444,029	370,658	192,219	158,324	118,069
WA	2020	12,804	10,481	14,877	12,182	14,699
	2050	69,451	57,153	58,374	47,981	42,459
	2070	125,022	103,453	71,696	58,992	48,154
	2100	188,714	157,198	81,036	66,719	49,706
Aust	2020	184,417	149,809	214,145	174,027	209,836
	2050	936,876	768,295	790,352	646,834	573,326
	2070	1,652,762	1,368,892	966,202	792,201	648,707
	2100	2,436,514	2,041,988	1,089,755	894,506	669,637

Figure 8 **Expected annual number of bacterial gastroenteritis cases in Australia due to climate change for each of the five temperature scenarios. Estimates include the modelled cases of salmonellosis**



Key messages

There are currently approximately 7500 notified cases of salmonellosis annually in Australia, but under-reporting (estimated to be by a factor of seven (Hall et al. forthcoming) means that the actual number of cases could be 52500. Symptoms of salmonellosis range from mild to severe, sometimes requiring hospitalisation. Deaths are rare, but complications can include dehydration and, occasionally, septicaemia. Those most at risk of serious illness are very young children and the elderly, and those with chronic disease. *Salmonella* can be present in raw or undercooked animal foods, or in any food that has been in contact with these or with contaminated implements or surfaces. It can also be spread from person to person or from contact with infected animals.

There is strong evidence of a relationship between ambient temperature and *Salmonella* infection in Australia[18] and elsewhere.[35,37] Annually, *Salmonella* notifications peak in summer and the rate of notifications has been shown to be positively and largely linearly associated with the mean temperature of the previous month[18] or week.[35,37] Although some of the increase in summer months may be due to changed eating behaviours (more 'eating out' while on holidays and attending outdoor functions such as barbecues), ambient temperatures contribute directly to pathogen multiplication in foods and thus likelihood of infection.[35,38]

Notification rates of *Salmonella* infection are expected to increase in future as climate change causes ambient temperatures to rise above the previous average, contributing to around 1000 extra cases annually by 2050 under the U1 scenario, or 580 under the M4 scenario. This relates to an annual difference of approximately 1200 lost workdays and $120,000 in the cost of health care and surveillance by 2050. These estimates were derived using notifications and do not take into account likely under-reporting. The actual impact of climate change on salmonella is likely to be around seven times higher.

Further, climate is likely to act on some other forms of gastroenteritis bacterial pathogens in a similar way as it does for *Salmonella*. Although we cannot directly predict the effect of climate change on other enteric pathogens, the consistent evidence for relationships between temperature and notifications for bacterial pathogens enabled broader estimates for climate change impacts to be made.

When potential (and, by necessity, crudely estimated) climate change impacts are applied to the proportion of gastroenteritis cases that are of bacterial origin, then the estimates for 2050 rise to 335,000 new cases, over $92.3 million dollars in health and surveillance costs and 1.6 million lost workdays under the U1 scenario. The lower estimate, under the M4 scenario, is for 205,000 new cases, $56.5 million and 570,000 lost workdays.

The number of future cases for the Northern Territory are likely to be underestimated in this model due to the application of the temperature relationship for Brisbane (which may be inadequate), and particularly in the second half of the century with the population projections that were applied (population growth slows).

In the Northern Territory, Indigenous children currently make up a substantial proportion of gastroenteritis cases (Peter Tait, personal communication). Assuming there is continued paucity of proper food preparation and storage facilities (refrigeration) and clean water available to Indigenous families in the coming decades, the effects of climate change on *Salmonella* notifications among Indigenous people will be disproportionately severe. Furthermore, the proportion of Australia's population that is Indigenous is increasing, so that the relative number of people living without adequate means to prevent infection is likely to increase.

Under-reporting and incomplete notification means that uncertainties are inherent in the data, while the precise temperature-notification relationships are not as 'clean' or have not yet been established in Australia for bacterial pathogens other than *Salmonella*. The results therefore presented here provide only a rough estimate of the future costs of Salmonella and other bacterial gastroenteritis.

These estimates are based on expected annual average temperatures, and thus do not account for the possibly differing temperature relationships in different seasons. For example, the summer season peaks may be more prolonged, as well as higher, and the changing shape of the seasonal patterns may contribute more to numbers of cases than represented here.

The increase in bacterial gastroenteritis could have significant implications for treatment success, without the advent of novel therapies, if the general trend towards antibiotic resistance continues. Of particular concern is that more severe cases of salmonellosis and other forms of gastroenteritis among the elderly in Australia will become more frequent as the population ages and the climate warms. People with compromised immune systems and those living institutionally, such as in aged care facilities, will be at particular risk.

Prevention

As Australia experiences warmer temperatures with climate change, the incidence of salmonellosis and other bacterial gastroenteritis is expected to increase. Transmission of bacterial pathogens can be reduced with proper food handling and storage and good hygiene. Regulation and enforcement of appropriate industry standards alongside and public education campaigns to promote good practice could reduce the expected impact of climate change on all enteric infections. Institutions such as hospitals and aged care facilities will need to take particular care. Improved tracking of foods and ingredients throughout production and transport, and the speedy investigation of outbreaks, would facilitate a more rapid recall of contaminated food and reduce disease. Such measures would increase the annual costs of surveillance and control beyond the estimates we have made here.

2.3 Dengue

Methods and assumptions

Health, climate and population data

We used an empirical model[39] (Hales *et al*. 2002) to estimate the population living in a region climatically suitable for dengue transmission. This model was developed from a regression of climate parameters with the reported distribution of dengue epidemics around the world for the period 1975–

1996. While it would be preferable to use a model developed on the basis of analysing the relationship between dengue occurrence and climatic conditions using Australian data alone, and at geographic higher resolution, no such model yet exists, and nor could such a model give a 'pure' relationship, since types and levels of interventions and quality of case detection and recording have varied over the decades.

The climate variable that predicted dengue epidemics most accurately was long-term humidity, expressed as average annual vapour pressure (from the baseline climate period of 1961–1990). The survival of a mosquito, which dictates whether it can live long enough to have multiple blood feeds, is strongly related to moisture and humidity levels. Other connected climatic factors, such as ambient temperature, influence the life cycle rate and geographic distribution of mosquitoes (latitude and altitude).

We obtained annual average vapour pressure and temperature baseline data for each Statistical Division[20] for the period 1961–1990 from CSIRO (OzClim[19]). Relative humidity was calculated by dividing the annual average vapour pressure by the estimated annual average saturated vapour pressure (via standard meteorological conversion formulae). The estimated changes in relative humidity were then added to the baseline relative humidity values. Finally the future temperature and relative humidity projections provided by CSIRO were converted into projected vapour pressure.

The output of the model was a number between zero and one, representing the probability that one or more epidemics of dengue fever would have occurred in a given location under baseline climate conditions. Regions were defined as 'at risk' of dengue where the model indicated a greater than 50% probability of transmission.

Future projections of total population were estimated for Statistical Divisions (SDs). We obtained the estimates for the capital cities and 'rest-of-state' areas for each State and Territory between 2004 and 2100, described previously. The capital city estimates from this dataset were used for the entire period; the rest-of-state estimates were adjusted to reflect predicted trends in the SDs within them. For this we used an earlier set of SD population predictions from 2004 to 2019[40] to interpolate SD populations from 2020 to 2049 to the Australian Bureau of Statistics (ABS) estimate for 2050.[41,42] In the absence of sub-state level projections from the ABS from 2050–2100, we made the simplifying assumption that the proportional contribution each SD made to the rest-of-state totals up to 2050 would remain for the rest of the century. On this basis, we estimated the rest-of-state population totals for the period 2051 and 2100, taking the ABS 2100 values as the endpoint.

Estimating baseline health costs

Number of cases

200 confirmed cases and 120 sub-clinical cases per year.[43,44]

- Since 1991 (17 years), the total number of *confirmed* indigenous (i.e. not imported) dengue cases in far north Queensland is estimated to have been 3385.[43,44] In addition to these, there have also been an unknown number of subclinical cases (i.e. cases of infection where symptoms are minor and do not require a doctor visit). A likely estimate is of a clinical to sub-clinical ratio in this region during this period of around 1:0.6, making a total of approximately 3000 sub-clinical cases in 17 years. The population of the far north Queensland at-risk areas (Cairns, Townsville and the Torres Strait) in the 2007 census was 430,000. The annual average number of confirmed cases was 47/100,000 (200), with an additional estimated 28/100,000 sub-clinical cases (120). There were four deaths from dengue haemorrhagic fever (DHF) and at least one from dengue encephalopathy—on average 0.5 of a hospitalisation and death per year.

Public health system costs per year

The annual public health and health care cost of dengue is estimated at an average of $2.82 per person in the population. This is comprised of:

- Surveillance and control: $2.56 per person. Aggressive case-finding and mosquito control are the major defences against epidemics and the risk of dengue haemorrhagic fever. Annual cost in Far North Queensland is $1.1 million a year (for vector surveillance and control, health education, case ascertainment and follow-up, and training of specialist staff).[40]

- Diagnostic costs: 19c per person.[44,45] Approximately three times the number of diagnostic tests are conducted for dengue and associated viruses as the number of confirmed tests. For the baseline annual number of 200 dengue cases there might be 600 tests performed. Routine testing during the year might results in another 50 tests being conducted—650 in all. Approximately half these (325) would be PCR and the other half IgM ELISA. The QLD Health Scientific Services has costs of $75 for PCR tests (~$24,500) and $180 (~$58,500) for ELISA tests.

- Treatment costs: 7c per person.[44] On average, two visits are made to a general practitioner (one to seek a test, and another to get the results). Additional follow-up checks are required for a smaller percentage of cases (10%). A standard Level B GP consultation is $55. Assuming all confirmed cases and 50% of unconfirmed cases attend a GP 2.1 times in an average year, this makes 546 visits at a cost of approximately $30,000.

- Hospital costs: Deaths to date have been rare and generally occur before protracted hospital stays incur notable system costs.

Assumptions and limitations involved in the dengue cost estimates:

- The figures for baseline costs were taken from 2006–2008 costs. We have not accounted for any variation in costs over time. Our assumption (probably conservative) was that the per person cost will remain the same in future, and that the pattern of dengue in Australia will also remain the same (i.e. epidemic).

- If dengue becomes established in Australia, the associated health system costs are likely to increase substantially above the baseline per person amount. First, unlike the present, there would not be years with very low or no cases of dengue recorded. Second, a much larger campaign of mosquito eradication would be needed across the endemic towns and cities. This would involve trained personnel, broad scale and intensive community education, and mosquito spraying. Currently this work is only focused on 'hot spots'—the local areas (usually sections or suburbs) where cases have been identified in a particular season.

- As dengue is not endemic in Australia, all outbreaks begin from an infected person who has travelled here from another country. We have made no assumptions about future changes in tourism levels on the introduction of dengue cases. If tourism were to increase markedly (especially to and from dengue-endemic countries), this might result in more outbreaks in Australia. The opposite is also the case. As well, the introduction of other serotypes of dengue (and hence the risk of outbreaks of the more serious complication of dengue haemorrhagic disease) will also come from tourists (residents returning or foreign tourists). This is a random event, and we have not modelled the possible consequences and costs involved. However, increasing tourism also raises the risk of this potentially fatal disease.

- Estimating the annual average number of dengue cases at present is difficult. Dengue outbreaks in non-endemic regions like northern Australia are by nature sporadic: in some years the number of cases are very high, and in others they are non-existent. In addition to this, many of the populations that have been exposed to dengue have been completely susceptible and so more vulnerable to infection. For example, in Charters Towers in 1993 26% of the non-immune population were infected in one outbreak.[46] The extent to which this might cause an overestimate of the annual number of cases, compared to several decades hence, is hard to predict. For this study we used a reasonably long time series (17 years) of high quality health records.

- Globally, the severity of dengue symptoms varies enormously. Factors that affect disease severity include ethnicity, age, nutritional status, the exact sequence of two different dengue infections, the genotype of the infecting virus, and the competence of the clinical and laboratory surveillance systems. We assumed that the future health system, demographic, social, and environmental influences on disease severity will broadly represent those of today.

- We have assumed that the average number of DHF cases is not likely to increase in future. The four cases of dengue haemorrhagic fever (DHF) between 2003–04 were aged 32 to 70 years. In contrast, in southeast Asia, dengue haemorrhagic fever predominantly occurs among children. A possible explanation for the older age of patients in northern Queensland is the long period between the dengue 1 and dengue 2 epidemics in this region, which means that only older people were susceptible. If outbreaks of different dengue serotypes occur more frequently in future (due to random chance or higher tourism numbers) or if dengue became established, this would probably change the age profile of DHF to include younger people as well. The labour costs of these would be small.

Estimating baseline labour costs

The annual labour cost is estimated to be 5 days per 1000 people (0.005 days per person).

- The average age of people infected with dengue from the outbreaks in Queensland is 36 years.[3] National data shows that 87.5% of people infected with dengue are aged 15–65 year, 7% are aged 0–15 years, and 5.5% are aged over 65 years. We have excluded the 5.5% of people over 65 years from this analysis, on the basis that most people in this age group are not in the paid workforce. We assumed that a person of working age would be required to stay at home and care for a child sick with dengue.
- People with clinical symptoms take an average of 10 days off work. People with sub-clinical symptoms take an average of 2 days off work.
- Therefore, average workdays lost per year during the baseline = [200*0.945 confirmed cases * 10 days =1890] + [120*0.945 suspected cases * 2 days =227] = 2117/430,000, or 0.005 days per person per year.

Assumptions include:

- People with dengue, especially adults, may not recover completely after the fever disappears. They may continue to experience physical discomfort, which can interfere with normal sleep, school or work patterns.[47] The effects of this delay in full recovery on work productivity have not been sufficiently studied to quantify for this study.
- More detailed research on this area could estimate the future participation rate of older people in the workforce—as the average age increases, so would the percentage of people over 65 who would lose workdays due to dengue disease. Similarly, we have assumed that a full-time working person would be involved in caring for a sick child. This is likely to be slightly less, as not all parents are in full-time employment.

Main findings

Under the warmer and wetter U3 scenario the geographic region suitable for the transmission of dengue is expected to move far south from its current position, as far as northern NSW by 2100. The regions at risk also include all the coastal areas of Queensland. The various mitigation scenarios all show far less expansion of areas suitable for dengue transmission. The percentage increases in the number of people at risk from dengue under the U scenarios and the mitigation scenarios are shown in Table 14. Total numbers are shown in Figure 9.

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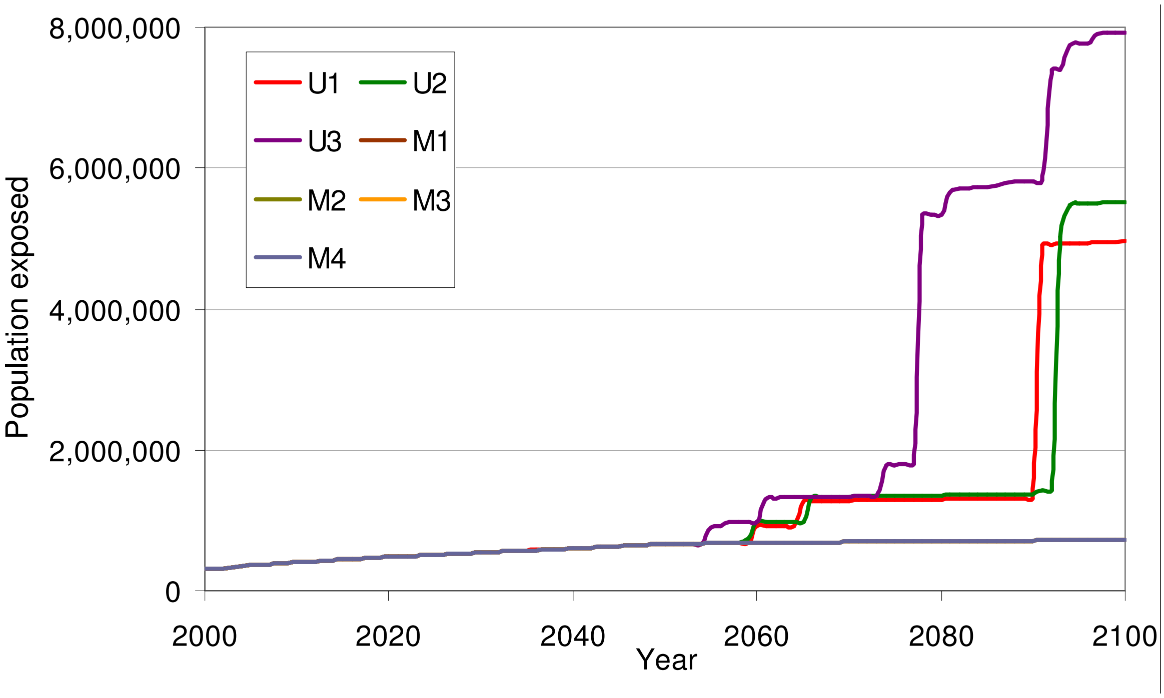
[3] Based on 457 cases from the 2003 DENV 2 outbreak (Far North Queensland Health Service records).

Table 14 **Estimated number of people exposed to dengue fever in Australia, percentage change from present (2000), associated health costs, and the number of lost workdays for mitigation and non-mitigation scenarios**

Year	U1	U2	U3	M1	M2	M3	M4
Percentage change in people exposed to dengue							
2020	+55	+55	+55	+55	+55	+55	+55
2050	+114	+114	+114	+114	+114	+114	+114
2070	+313	+332	+332	+124	+124	+124	+124
2100	+1500	+1680	+2500	+133	+133	+133	+133
Number exposed to dengue (millions)							
2020	0.48	0.48	0.48	0.48	0.48	0.48	0.48
2050	0.66	0.66	0.66	0.66	0.66	0.66	0.66
2070	1.28	1.34	1.34	0.7	0.7	0.7	0.7
2100	4.96	5.52	7.93	0.72	0.72	0.72	0.72
Health costs (millions)							
2020	1.35	1.35	1.35	1.35	1.35	1.35	1.35
2050	1.87	1.87	1.87	1.87	1.87	1.87	1.87
2070	3.61	3.78	3.78	1.96	1.96	1.96	1.96
2100	13.99	15.57	22.36	2.04	2.04	2.04	2.04
Work days lost per year							
2020	2,400	2,400	2,400	2,400	2,400	2,400	2,400
2050	3,300	3,300	3,300	3,300	3,300	3,300	3,300
2070	6,400	6,700	6,700	3,500	3,500	3,500	3,500
2100	24,800	27,600	39,700	3,600	3,600	3,600	3,600

Figure 9 **The number of people living in a region suitable for the transmission of dengue infection, under different climate change scenarios. The step-changes observed for scenarios U1, U2 and U3 occur as climate change mean the range of the vector expands to include a new population centre. NB. The mitigation scenarios (M1-M4) result in identical numbers of people at risk, and are represented together by the blue (M4) line.**



The health costs and number of workdays lost are estimated to be the same under the mitigation and non-mitigation scenarios for the first half of the century. By 2070, expected annual health system costs for dengue under the U3 scenario increase to twice those of the mitigation scenarios. By 2100, these costs are projected to be more than eleven times as high.

If mitigation was achieved under any of the four scenarios presented by 2070, more than 3000 lost workdays a year could be saved compared to the U3 scenario. This amount increases to more than 36 000 workdays a year by 2100.

Discussion

Dengue fever is caused by infection with one of four serotypes of dengue virus. It is transmitted from human to human through the bite of the urban freshwater mosquito *Aedes aegypti*. Outbreaks occur in Australia when a mosquito bites an infected traveller and transmits the virus to a resident. The north and central areas of Queensland and the Northern Territory are considered potentially receptive to the establishment of dengue. Even though local transmission of dengue fever now occurs in most years in northern Queensland the virus is not yet endemic in Australia. Dengue infection causes a fever, general body aches, and occasional minor bleeding. Dengue haemorrhagic fever is a life-threatening complication that can result from a second dengue infection with a different virus serotype to that which caused the primary infection.[47] A large epidemic of dengue fever in Townsville and Charters Towers in 1992–1993 raised the possibility of the re-emergence of dengue haemorrhagic fever in Australia. Epidemics of dengue appear to have recently become more regular in north Queensland, with five major epidemics (three affecting the Torres Strait) and many smaller epidemics between 1992 and 2004. In contrast, the five previous epidemics occurred over 90 years.[48] Increasing international travel into north Queensland and the global amplification in dengue activity have been proposed as the main reasons for this rise. The substantial control measures instituted by public health authorities over this period may have averted more frequent and larger epidemics.

Factors other than climate also influence the transmission dynamics of dengue. For example, the ‘Asian tiger’ mosquito (*Ae. albopictus*) has been observed in far northern Australia. This mosquito is more cold tolerant than *Ae. Aegypti*, and if it becomes established it could be a more efficient vector than *Ae. Aegypti* in southern temperate regions. This could mean that regions further south than this modelling predicted could also become suitable for dengue transmission. The risk of the introduction of other dengue serotypes (and thus the increased risk of outbreaks of dengue haemorrhagic fever) rises as the number of tourists from countries in Asia and the Pacific increases.

The complexity of prevention and management is high for dengue, and outbreaks can spread rapidly within a population. Aggressive case-finding and mosquito control are the main defence against further epidemics and the attendant risk of dengue haemorrhagic fever. The main vector, *Ae. Aegypti,* prefers to breed in the urban environment and to feed on humans, often during the daytime. Prevention of infection requires attention to clearing or treating domestic containers and pot plants that hold water, and to applying mosquito repellent during outbreaks. Once established in a country, dengue virus can be extremely difficult to eradicate. Countries in our region with high per capita wealth, such as Singapore, have struggled to contain very large epidemics of dengue fever—despite high public health expenditure, extensive education campaigns, and regulatory measures designed to encourage household-level eradication of mosquito larvae.

While the total number of people infected each year is predicted to gradually increase this century as the regions exposed to dengue also expands, we have assumed that the future annual *rate* of dengue cases is not likely to increase above the current rate. This depends on ensuring that the virus does not become established, and that the public health response expands forcefully into regions that become at risk. This will involve increased funding in these areas for mosquito surveillance and control, and for trained entomologists to provide confirmation that a case of dengue infection has been locally acquired. Mechanisms for the rapid establishment of dengue-response teams in new regions and information sharing will also be important to establish in advance of an outbreak.

3 Conclusions

We modelled estimates for three health outcomes under the different climate scenarios to 2100.

The impacts on temperature-related deaths and hospitalisations vary considerably between States and Territories, with the greatest negative impacts occurring in Queensland, the Northern Territory and Western Australia. Some modest reductions in cold-related deaths are expected in colder regions as the temperature rises, but by the end of the century these are outweighed by the increases in heat-deaths in these regions.

The number of cases of gastroenteritis will rise over the coming century, due to increases in cases caused by *Salmonella* and other bacteria. Bacterial pathogens currently comprise 36% of all gastroenteritis cases in Australia, and it is these cases that climate change will have the most direct impact upon, rather than gastroenteritis of viral or parasitic origin which does not have a readily demonstrated relationship to ambient temperature. The relationship to climate of these other causes may be more complex and depend on factors such as changing rainfall and patterns of outdoor activity.

Under the scenarios presented here, climate change will cause, annually, between 205,000 and 335,000 new cases of bacterial gastroenteritis by 2050, or between 239,000 and 870,000 cases by 2100. The difference in annual health care and surveillance costs between the highest temperature change scenario (U1) and the lowest (M4) is estimated to be $35.8 million by 2050 and $174.2 million by 2100, while the difference in the annual number of workdays lost is 364,000 by 2050 and 1.8 million by 2100.

Under the warmer and wetter U3 scenario the geographic region suitable for the transmission of dengue is expected to move far south from its current position, as far as northern NSW by 2100. By 2070, expected annual health system costs for dengue under the U3 scenario increase to twice those of the mitigation scenarios. By 2100, these costs are projected to be more than eleven times as high. If mitigation was achieved under any of the four scenarios presented by 2070, more than 3 000 lost workdays a year could be saved compared to the U3 scenario. This amount increases to more than 36 000 workdays a year by 2100.

The estimated population health outcomes presented here addresses only part of the total future risk to population health in Australia. We judge that these three health impacts account for no more than one third of the total definable health burden from climate change.

The modelled projections presented here do not include anticipated variability in future climate but were based on average change, and nor do they consider capacity for adaptation. Future models will be improved by including these factors. For example, we were unable to include estimates of physiological and behavioural adaptation into the temperature and mortality models as these are currently unknown. To date there has been limited research, and research funding, for this important line of work in Australia.

Appendix A Notes on mortality, YLL and hospitalisations spreadsheet output

General

On all sheets, blocks of derived values, to be calculated within the spreadsheet, are indicated with pale blue background. Formulas are entered in the top row, and should be dragged down to fill the blue cells. This is done to minimise file size.

Notes to workbook 'YLL' (years of life lost)

Values in this workbook are millions of working days lost due to heat-related deaths.

Appendix B Notes on *Salmonella* spreadsheet output

Explanation of variables

Salmonella

SalmonellaPopChangeOnly—Number of cases of Salmonella that would occur in the absence of climate change (considers population change only)—‘Business as usual’

SalmonellaCCOnly—Number of cases of Salmonella that would occur in the absence of population change with climate change only

SalmonellaCCAndPop—Number of cases that would occur considering both population and climate change

SalmonellaNewCasesFull—Number of new Salmonella cases annually (compared to baseline year 2001), considering both population and climate change

SalmonellaClimateVsBAU—Number of new Salmonella cases annually (compared to baseline year 2001) that would occur due to climate change (i.e. takes out the number of cases due just to demographic change). Climate change effect on top of ‘business as usual’ (no climate change)

HealthCostClimate(Salm)—Health costs of climate change vs BAU

SafetyCostClimate(Salm)—Safety and surveillance costs of climate change vs BAU

TotalCost(Salm)—Total costs (Health and Safety summed)

WorkDaysClimate(Salm)—Number of workdays lost from climate change vs BAU

All bacterial gastro

GastroPopChangeOnly—Number of cases of Salmonella that would occur in the absence of climate change (considers population change only)—‘Business as usual’

GastroCCOnly—Number of cases of Salmonella that would occur in the absence of population change with climate change only

GastroCCAndPop—Number of cases that would occur considering both population and climate change

GastroNewCasesFull—Number of new Salmonella cases annually (compared to baseline year 2001), considering both population and climate change

GastroClimateVsBAU—Number of new Salmonella cases annually (compared to baseline year 2001) that would occur due to climate change (i.e. takes out the number of cases due just to demographic change). Climate change effect on top of ‘business as usual’ (no climate change)

HealthCostClimate(Gastro)—Health costs of climate change vs BAU

SafetyCostClimate(Gastro)—Safety and surveillance costs of climate change vs BAU

TotalCost(Gastro)—Total costs (Health and Safety summed)

WorkDaysClimate(Gastro)—Number of workdays lost from climate change vs BAU

Appendix C Notes on dengue spreadsheet output

- The first year in the period is the year 2000.
- Data for the whole of Australia and each State and Territory affected are the number of people exposed to dengue transmission (‘count of people exposed’) and percentage change in people exposed since 2000 (‘% change since 2000’).
- States or Territories which were not exposed to dengue at the year 2000 (i.e. everywhere except for QLD and the NT) do not have a column giving percentage change in people exposed since 2000.

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