ECONOMIC MODELLING TECHNICAL PAPER 4

METHODOLOGY FOR MODELLING THE ECONOMIC EFFECTS OF CLIMATE CHANGE

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CLIMATE CHANGE REVIEW

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This is the fourth in a series of Technical Papers of the Garnaut Climate Change Review's discussion of the methodology and results of Modelling of the Net Costs of Climate Change Mitigation. Other Papers in the series, available on the Review's website www.garnautreview.org.au are as follows:

Technical Paper Number 1: Overview and approach to the economic modelling

Technical Paper Number 2: Climate data, methodology and assumptions

Technical Paper Number 3: Assumptions and Data Sources

Technical Paper Number 4: Methodology for modelling climate change impacts

Technical Paper Number 5: Modelling the costs of unmitigated climate change

Technical Paper Number 6: Global Climate Change Mitigation: Implications for Australia

Technical Paper Number 7: The net costs of global mitigation for Australia

1 Introduction

This paper discusses the key areas of impact from climate change that have been modelled by the Garnaut Climate Change Review (the 'Review'). As discussed in Technical Paper 1, these are the Type 1 costs of climate change – they are the impacts that could be measured with enough certainty to be modelled in the general equilibrium framework used by the Review (the Monash Multi Regional Forecasting Model). They do not cover all of the expected market impacts of climate change.

A wide range of expertise has been utilised to determine the likely market impacts of climate change on:

- Primary production
- Critical infrastructure
- Human health
- Tropical cyclones.

Each of the impact areas that have been analysed by the Review are briefly discussed in turn below. A table summarising the shocks used in the modelling is provided at the end of this paper.

While this technical paper focuses on the methodology used by the Review to incorporate the direct impacts into the modelling framework, more detail on the initial estimation of the direct impacts is available. Various teams of experts were commissioned by the Review and have contributed to the estimation of the direct impacts of climate change. Each has provided the Review with a detailed report of their findings. These reports are available on the Review's website www.garnautreview.org.au.

2 Primary production

Climate change is expected to reduce the productive capacity of Australian livestock industries. The productivity of these industries will be influenced by the changes in quantity and quality of available pasture. Further, the likelihood of severe temperatures can be expected to induce heat stress in livestock.

2.1 Livestock

Sheep and Beef Cattle

The implications of climate change for the Sheep and Beef Cattle industries were estimated by the Queensland Climate Change Centre of Excellence (QCCCE). QCCCE used a formal modelling approach to determine the likely changes to pasture production, and hence livestock carrying capacity, from projected changes to atmospheric CO_2 concentrations, temperature and rainfall.

In deriving a final model for simulating national carrying capacity, eleven models were initially developed and compared. The eleven models were based on combinations of simulated pasture variables from the soil-water balance and pasture growth model GRASP (Rickert et al. 2000, McKeon et al. 2000), alternative treatments of the arid zone and either inclusion or exclusion of a livestock production index.

To parameterise the GRASP model for each climate location, pasture growth attributes were drawn from the AussieGRASS national modelling framework (Carter et al. 2000).

Eleven different models were compared using sensitivity tests with various climate change scenarios. The selected model was regarded as a conservative representation of the effects of climate change in the arid and semi-arid zones, while providing reasonable explanation of existing spatial variation in livestock carrying capacity (LCC) in higher rainfall zones in southern Australia.

Table 1 contains the equations derived by QCCCE to estimate the change in carrying capacity for each region through time. A report on the methodology use to these equations is available of the Review's website (see McKeon et al. 2008)

Table 1 Response functions derived by QCCCE for each state

EQUATION: Percentage change in carrying capacity =

$$a + b(Dt) + c(Dr) + d(C) + e(Dt \times Dr) + e(Dt \times C) + f(Dr \times C) + g(Dt^2) + h(Dr^2) + i(C^2) + j(Dt \times Dr \times C)$$

where:
Dt = Delta T (Change in temperature [deg C])
Dr = Delta R (Change in Rainfall)
C = absolute Co2 concentration (ppm)

COEFFICIENTS:

State	a	b	c	d	e	f	g	h	i	j	k
NSW	-2.48	-1.91	1.23	0.01	-0.02	0.00	0.00	-0.04	2.3E-03	-3.5E-06	1.5E-05
VIC	0.69	0.21	1.00	0.00	-0.01	0.00	0.00	-0.13	-2.5E-04	8.1E-07	1.1E-05
QLD	-5.08	-4.62	1.33	0.02	-0.03	0.00	0.00	0.24	3.7E-03	-7.0E-06	2.8E-05
SA	-1.75	-1.46	1.46	0.01	-0.03	0.00	0.00	-0.16	4.4E-03	-2.6E-06	1.5E-05
WA	-2.70	-0.99	1.27	0.01	-0.02	0.00	0.00	-0.14	2.7E-03	-3.6E-06	1.2E-05
TAS	-1.31	-0.34	1.05	0.00	-0.02	0.00	0.00	-0.20	3.1E-04	-1.5E-06	4.3E-06
NT	-4.49	-3.44	1.19	0.01	-0.03	0.00	0.00	0.01	2.0E-03	-5.9E-06	2.2E-05
ACT	-3.34	2.88	0.94	0.01	-0.01	0.00	0.00	-0.47	-8.8E-04	-4.0E-06	-2.8E-06

Source: McKeon et al, 2008

QCCCE's modelling suggests that climate change is likely to have significant adverse impacts on the carrying capacity of Australia's grazing lands. Table 2 contains a summary of the results from the response functions shown in Table 1 above.

Table 2 Summary of the results from the response functions derived by QCCCE[1].

Climate scenario	Year	NSW	VIC	QLD	SA	WA	TAS	NT	ACT
Median no-mitigation	2020	-2.6	-2.2	-3.6	0.6	-3.5	-0.9	-3.1	0.2
	2050	-8.0	-7.0	-10.0	2.0	-11.2	-3.0	-9.3	-0.8
	2100	-17.8	-17.0	-16.3	5.1	-27.6	-8.2	-18.7	-9.2
Extreme dry no-mitigation	2020	-8.9	-5.3	-12.0	-12.8	-10.7	-3.6	-10.5	-3.0
	2050	-27.5	-17.1	-35.3	-38.9	-33.4	-11.8	-31.8	-11.9
	2100	-62.2	-43.2	-70.6	-82.8	-76.8	-30.0	-69.5	-40.4
Strong mitigation to 550 ppm	2020	-2.9	-2.3	-4.0	-4.8	-3.8	-1.0	-3.5	0.1
	2050	-7.4	-5.9	-9.9	-12.3	-10.0	-2.8	-9.0	-0.9
	2100	-9.3	-7.4	-12.1	-15.5	-12.6	-3.6	-11.2	-1.6
Ambitious mitigation to 450 ppm	2020	-3.4	-2.7	-4.7	-5.6	-4.4	-1.2	-4.1	0.0
	2050	-6.8	-5.2	-9.3	-11.2	-9.1	-2.5	-8.4	-0.9
	2100	-7.4	-5.6	-10.1	-12.0	-9.9	-2.8	-9.2	-1.1
Strong mitigation to 550 ppm under extreme drying	2020	-9.6	-5.6	-13.0	-13.8	-11.5	-3.9	-11.4	-3.3
	2050	-24.0	-14.4	-31.5	-33.7	-28.9	-10.2	-28.1	-10.1
	2100	-29.7	-18.1	-38.4	-41.4	-35.9	-12.8	-34.7	-13.4

Source: McKeon et al, 2008

The projected changes to output for sheep and beef cattle, as estimated by the QCCCE response functions, were converted to changes in all factor productivity for use in MMRF. This methodology

[1] The slightly higher responses to climate change under the mitigation scenarios in the year 2020 are driven primarily by the higher temperatures under mitigated climate change in the early period as a result of aerosols. This issue is discussed in Technical Paper Number 2.

has been used in agriculture modelling in the past (eg Adams et al. 2002) and is discussed further in Box 1.

Box 1 Translating primary production projections to primary factor productivity shocks for use in MMRF

Each of the expert groups commissioned by the Review used partial equilibrium (PE) frameworks to determine the likely response of primary industry production to a changing climate.

PE models make simplifying assumptions about the rest of the economy since they generally focus on a single sector (for example, it is common to assume that prices are fixed). While these simplifying assumptions allow the effects on a particular sector to be modelled with greater detail than is available in a General Equilibrium (GE) model like MMRF, they are not linked into the broader economy and therefore do not consider the feedback effects from changes occurring in other sectors nor do they consider the effect of behavioural responses of other economic agents (such as households).

Because of this, the Review did not directly impose the production projections from the PE modelling in MMRF. Rather, the PE modelling projections were used to inform changes to primary factor productivity in MMRF. The equation below illustrates how productivity changes affect output in a GE framework such as MMRF:

$$\text{Activity} = \frac{f(L, K, N)}{A}$$

Where

L is labour

K is capital

N is land

$^1/_A$ is productivity

The equation shows that industry activity is a function of productivity and the primary factors of production (land, labour and capital). If factors of production (L, K, N) are held fixed, a one per cent change in productivity ($^1/_A$) implies a one per cent change in output.

In a GE framework like MMRF, changes to the production process (such as would be caused by changes to productivity) will trigger price movements. Demand will respond to this price movement (a movement along the demand curve) and a new, equilibrium level of output for the industry will be determined. If demand for a good is elastic, that is, the quantity consumed is sensitive to price movements, an increase in prices would cause a fall in output. However, if demand is inelastic, that is, the quantity consumed is somewhat insensitive to price movements, output will remain high but more resources will be needed to maintain production.

For example, if productivity in the dairy industry declined, there would be an increase in primary factor requirements to sustain production and thus the price of dairy products would increase. Household consumption of dairy products is assumed to be relatively inelastic, that is, the quantity consumed is somewhat insensitive to price movements. Hence, the dairy industry will sustain production, despite the need to increase primary factor usage, as the increase in cost can be passed on to the consumer. There will be significant economic costs, despite the fact that dairy production levels are maintained, since the dairy industry will divert scarce resources (labour and capital) from other sectors.

As illustrated by this example, imposing the PE production estimates as productivity shocks allows MMRF to capture:

- the impact on the activity of the relevant industry, as estimated in the PE framework;
- the impact on other sectors in the economy;
- the feedback effects from those sectors to the original industry; and
- the macroeconomic implications.

2.2 Dairy

Whilst no formal modelling was undertaken, the Review undertook research to estimate impacts on the Dairy industry with advice from QCCCE, the Risk and Sustainable Management Group at the University of Queensland and the opinion of other experts in the field[1].

It is expected that climate change will have a significant impact on pasture growth (McKeon et al. 2008). Additionally, the dairy industry in the Murray Darling basin is likely to be affected by reductions in stream flow given that the industry currently relies on irrigation water for pasture improvement (Quiggin et al. 2008). It is also anticipated that heat stress will have a negative impact on milk production in dairy cows where production losses increase exponentially with increases in heat (Jones & Hennessey 2000).

The Dairy industry is likely to respond to a changing climate in three ways:

- A shift to dryland dairy with increased use of supplementary feedstock
- A shift to capital intensive dairy production, with total reliance on supplementary feedstock
- Investment in additional infrastructure to cool dairy cattle in times of extreme heat.

The Review modelled this response through:

- changes to primary factor requirements of the *Dairy* industry per unit of output (as outlined in Box 1)
- changes to the usage of supplementary feedstock by the *Dairy* industry.

2.3 Other livestock

The Review did not commission an impact assessment for other livestock such as chickens and pigs. This had implications for the assumptions made when incorporating the livestock industry impacts in the modelling. These assumptions are discussed below.

Assumptions and limitations

The methodology used to incorporate the estimated livestock production impacts in the whole-of-economy modelling is subject to a number of key assumptions and limitations:

- It is possible that, as the cost of meat and dairy production in Australia rises, we will begin importing these commodities. However, is difficult to predict the effect unmitigated climate change would have on the cost of meat production outside of Australia. Given that meat and dairy consumption is projected to increase rapidly as incomes in developing nations increase, it is probable that imported meat and dairy would not be competitive with domestically produced meat and dairy

- Meat produced by the livestock industry (mainly beef and lamb) is a reasonably close substitute for meat produced by intensive farming processes (mainly pigs and chickens). Ordinarily in the MMRF model, there is strong price driven substitution between these goods. However, the Review has not commissioned research examining the impacts of climate change on the production of intensively farmed animals like pigs and chickens. Since there exists a good understanding of the likely climate induced price movement for beef and lamb meat but not for pig and chicken meat, only weak substitution between these commodities is allowed

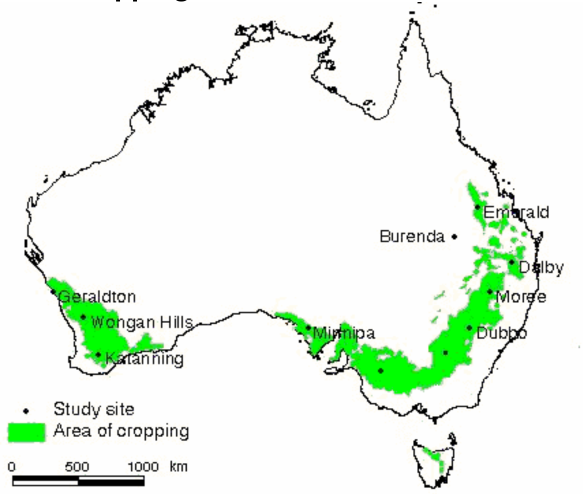
- During the latter half of the century significant reductions in rainfall, particularly for the extreme dry reference scenario, causes very large shifts in the carrying capacity of land used for live stocking. It is difficult to predict the likely economy-wide response to these kinds of changes with certainty.

2.4 Dry-land Grains Production

Climate change induced reductions in rainfall and increases in temperature will make it increasingly difficult to maintain grain production levels in Australia.

Impacts on Australia's wheat cropping have been estimated by the Commonwealth Science and Industrial Research Organisaion (CSIRO) Sustainable Ecosystems (see Crimp et al. 2008). In an assessment of ten study sites across Australia, CSIRO examined yield responses to a range of temperature, rainfall and CO_2 changes using the APSIM cropping systems modelling framework. CSIRO developed general response functions to express the likely wheat yield changes for specific sites distributed across the Australian wheat belt. Figure 1 illustrates the major areas of wheat cropping in Australia and the sites analysed by CSIRO. Table 3 contains the response functions derived by CSIRO.

Figure 1 Area of wheat cropping in Australia and the sites analysed by CSIRO



Source: CSIRO, 2008, *Global Climate Change impacts on Australia's Wheat Crops*.

Table 3 Response functions derived by CSIRO for ten study sites

EQUATION: Percentage change in yield =

$$[a(CO_2)+b(CO_2)^2+c(CO_2)^3+d(CO_2)^4+e(T)+f(T)^2+g(T)^3+h(R)+i(R)^2+j]\times 100$$

COEFFICIENTS:

Wheat growing area	j	a	b	c	d	e	f	g	h	i
Dalby	-3.4E+00	3.6E-03	-3.9E-06	1.8E-09	-3.1E-13	-1.0E-01	3.4E-02	-5.1E-03	3.8E+00	-1.2E+00
Emerald	-3.8E+00	3.2E-03	-3.6E-06	1.7E-09	-3.0E-13	-3.6E-02	1.1E-02	-1.8E-03	4.8E+00	-1.8E+00
Coolamon	-4.6E+00	2.6E-03	-3.0E-06	1.5E-09	-2.8E-13	-4.7E-02	5.1E-02	-8.8E-03	6.9E+00	-2.8E+00
Dubbo	-4.2E+00	3.4E-03	-4.0E-06	2.1E-09	-3.9E-13	1.8E-02	2.5E-03	-1.9E-03	5.9E+00	-2.5E+00
Geraldton	-2.0E+00	3.9E-03	-4.7E-06	2.4E-09	-4.7E-13	-4.2E-02	-9.2E-03	2.5E-03	2.4E+00	-1.2E+00
Birchip	-5.1E+00	4.7E-03	-5.3E-06	2.6E-09	-4.5E-13	9.7E-02	-3.8E-02	3.3E-03	5.0E+00	-9.0E-01
Katanning	-2.0E+00	2.6E-03	-3.3E-06	1.8E-09	-3.5E-13	1.5E-01	-5.7E-02	6.6E-03	2.8E+00	-1.4E+00
Minnipa	-3.3E+00	4.3E-03	-4.8E-06	2.4E-09	-4.3E-13	-4.1E-02	-6.7E-03	3.2E-03	2.2E+00	6.1E-02
Moree	-4.2E+00	4.1E-03	-4.7E-06	2.3E-09	-4.0E-13	1.2E-01	-5.9E-02	6.6E-03	4.5E+00	-1.3E+00
Wonganhill	-3.8E+00	4.2E-03	-4.9E-06	2.5E-09	-4.7E-13	8.5E-02	-3.6E-02	3.5E-03	4.6E+00	-1.7E+00

More detail of the impacts on Australia's wheat cropping, as estimated by CSIRO, can be found on the Review's website (see Crimp et al. 2008).

As discussed in Box 1, the CSIRO projections of changes to output for dry-land grains were converted to changes in the primary factor requirements of the industry per unit of output.

Assumptions and limitations

The methodology used to estimate impacts is subject to a number of key assumptions and limitations:

- While the CSIRO analysis is focused on wheat cropping, the impacts have been extended to include complementary crops on the advice of CSIRO. Hence, the relationship generated by CSIRO has been applied to barley, wheat and oat crops. Whilst they are likely to be affected, no climate change impacts have been incorporated in the modelling for other dry-land crops (eg. canola seeds, lupins, legumes for grains)

- Many of the limitations that apply to livestock also apply to dryland cropping. For example, under extreme climate scenarios it is difficult to predict the cost and requirements of imported produce as Australian crop yields diminish and domestic prices rise.

2.5 Irrigated agriculture

Climate change induced reductions to rainfall will result in much larger declines in runoff and stream flow, which will reduce the availability of water for irrigation. It will become ever more difficult to maintain irrigated agriculture activity under such conditions.

The research into the future of Australian irrigated agriculture, as commissioned by the Review, focuses on climate change impacts on primary production in the Murray Darling Basin (MDB). This research at the Risk and Sustainable Management Group (RSMG), University of Queensland (UQ) (see Quiggin et al. 2008). RMSG used their model to estimate irrigated agriculture activity based on the allocation of land and water in the MDB under uncertain and changeable climatic conditions. More detail on the RSMG analysis can be found on the Review's website.

Whilst more than 70 per cent of Australia's irrigated cropping activity occurs in the MDB (ABS 2007), there are other areas in Australia where significant irrigated cropping activity occurs (for example, the Ord River catchment in Western Australia and the Burdekin River catchment in Northern Queensland). The ABS classifications of irrigated crops and the shares of irrigated agriculture for each state and territory are shown in Table 4.

Table 4 State shares of Australian irrigated agriculture (%)

State	Cereals	Vegetables	Sugar Cane	Fruit and Nuts	Grape Vines	Other Crops	Cotton	Rice	Other Cereals
NSW	83.57	15.38	0.07	22.96	23.80	31.47	68.22	98.79	75.81
VIC	6.68	21.83	-	22.04	25.34	12.64	-	1.15	10.33
QLD	8.04	27.64	98.26	28.86	1.53	24.18	31.72	0.07	13.25
SA	0.80	12.14	-	15.84	42.62	13.25	-	-	0.00
WA	0.37	7.99	1.67	7.34	6.29	3.65	0.07	-	0.61
TAS	0.54	15.01	-	2.95	0.41	14.77	-	-	-
Territories	-	-	-	0.01	0.02	0.04	-	-	-

Source: Australian Bureau of Statistics (2004). AgStats on GSP (7117.0.30.001), Canberra.

There is a general lack of research into catchments outside the MDB and the Review did not commission such research. Estimating the impacts of climate change on other catchments is difficult because of the long time periods involved. However, it is likely that reductions in rainfall will adversely affect these other growing regions. For example, while there is most likely ample water to sustain current production levels of cropping in North Queensland even if rainfall declines significantly, there is likely to be significant growth in agriculture in North Queensland and hence additional strain on water supplies over the next century. Hence, not incorporating some concept about the impact of climate change on production in these other catchments would significantly underestimate the economic implications of reductions in the availability of irrigation water in Australia. In the absence of other information, it was assumed that changes to rainfall and runoff will affect irrigated agriculture production in similar ways across Australia. As a result, the relationships and impacts were applied to all areas. This was done independently by the Review, based on the analysis by Quiggin et al. 2008.

The modelling work undertaken by Quiggin and Adamson illustrates that the main explanatory variable for reduction in output is reduction in runoff. While there is a clear relationship between rainfall and runoff, it is non-linear. That is, small changes to rainfall can cause greater changes to runoff. This is illustrated for both the dry and median unmitigated climate scenarios in Figures 2 and 3. The changes to runoff and stream flow were calculated by QCCCE from CSIRO regional estimates of rainfall changes.[2]

Figure 2 Changes to rainfall and runoff under the unmitigated median scenario (Australian average)

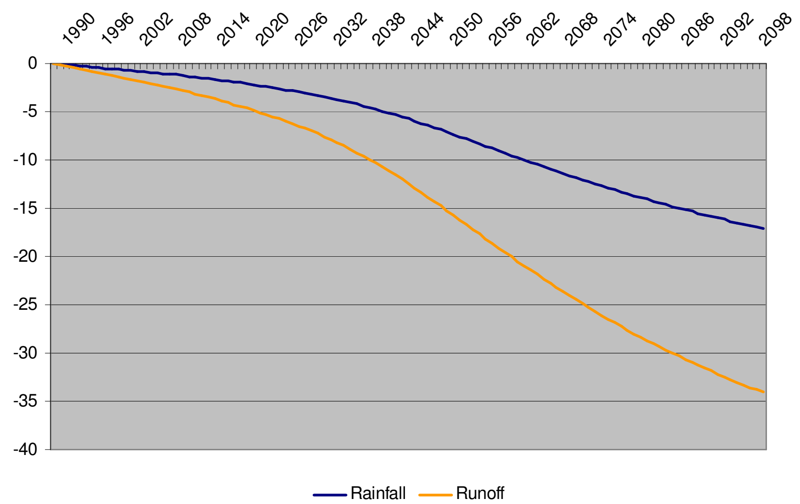
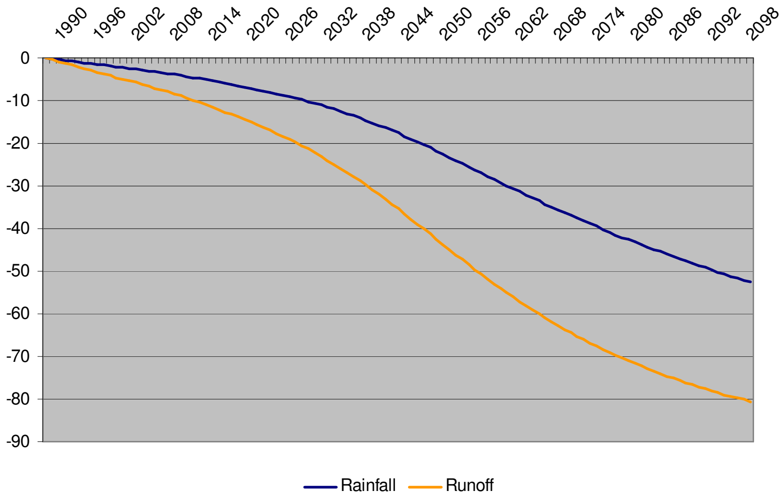


Figure 3 Changes to rainfall and runoff under the unmitigated dry scenario (Australian average)



The Review estimated a relationship between runoff and the value of production in the MDB. This estimated relationship was based on the QCCCE runoff projections and the production value estimates provided by Quiggin and Adamson. In the absence of other information, it was assumed that the relationship between runoff and value of output for the MDB holds in all major areas of irrigated agriculture across Australia. Estimates of lost production for each statistical division were calculated and weighted according to the statistical division share of irrigated land in the relevant state.[3] The resulting projections for declines in state production were translated into regional primary factor productivity shocks to the Grains and Other Ag industries in MMRF.

Assumptions and limitations

The methodology used to estimate impacts to irrigated agriculture is subject to a number of key assumptions and limitations:

- As mentioned above, there is limited research available that provides sound analysis of the impacts of climate change on irrigated agriculture outside the MDB. The Review has assumed that the relationship between runoff and output in the MDB can be extended to areas outside of the MDB. While experts[4] in the field agree that this is a plausible assumption, without further analysis of Australia-wide irrigated agriculture activity, this remains a shortcoming of the Review's methodology
- Accelerated coastal erosions and saltwater intrusion into coastal freshwater sources has not been considered. This could exacerbate the adverse impacts on irrigated agriculture in coastal areas, especially Northern Queensland
- The uncertainty of the industry structure and land use in the future adds another complicating factor in accurately predicting the climate change impacts on irrigated agriculture. The impact calculations are largely based on the current quantity of irrigated cropping land in each statistical division. The partial equilibrium analysis undertaken by RSMG is also based on the current state of the industry.

3 Critical infrastructure

General changes to climate, coupled with increased frequency and intensity of severe weather events, will result in substantial impacts on residential, commercial and industrial infrastructure throughout Australia.

Impacts on infrastructure have been estimated by Maunsell and CSIRO Sustainability Ecosystems. A range of qualitative and quantitative information, as well as expert opinion, was used to estimate impacts on four key areas:

- Buildings in Coastal settlements
- Electricity transmission and distribution networks
- Water supply infrastructure in major cities
- Port infrastructure and operations.

3.1 Buildings in coastal settlements

Increases in capital expenditure in coastal settlements will result under climate change. These costs will be incurred due to:

- Upgrading and repairing existing residential buildings
- Reduction in the life expectancies of residential, commercial and industrial buildings
- Increases in the cost of constructing new residential buildings (eg. cost of installing insulation and double glazed windows in new homes).

These impacts have been incorporated in MMRF as an increase in the capital requirements of dwellings and commercial buildings. For dwellings this is modelled as an increase in capital costs per unit of “output”. For industry, this is modelled as an increase in the expenditure required on building construction per unit of output.

Climate change is also like to result in increased maintenance expenditure arising from an increase in the extreme weather events and accelerated degradation of building materials.

Increased maintenance costs have been incorporated in MMRF as increases in the use of *construction services* by firms and households.

3.2 Electricity Transmission and Distribution

Accelerated materials degradation and a greater occurrence of extreme events will require changes in the design and early renewal/replacement of electricity distribution networks. This has been modelled as an increase the capital expenditure of the e*lectricity supply* industry in MMRF.

The increased extreme weather events and accelerated materials degradation associated with climate change is also likely to cause an increase in the operational requirements of the electricity transmission and distribution industry. This is modelled in MMRF as an increase in the purchase of equipment, construction services and labour inputs per unit of output for the *Electricity Supply* industry.

3.3 Water Supply

Climate change is likely to affect water supply in two ways. Firstly, it is likely to cause an increase in the operational and capital expenditures on existing infrastructure. Secondly, it is likely to force a change to the way in which water is sourced, particularly an increased reliance on alternative water supplies, such as desalination and water recycling.

On the first of these, climate change is likely to cause more severe flooding and drying events which will require significant capital and maintenance expenditures, particularly for pipeline and drainage infrastructure. These are modelled as an increase in expenditure on capital, equipment, *construction services* and labour per unit of output.

As water becomes more scarce (under the dry climate scenarios), the Water Supply industry is assumed to overcome supply shortfalls by producing water from non-traditional sources such as desalination and water recycling. These alternative water supply technologies are more capital and energy intensive than traditional water supply options (mainly dams).

The capital expenditures are estimated using industry knowledge and are somewhat independent of rainfall changes, since the infrastructure must be constructed as insurance against less reliable natural water supplies.

Operational expenditures, mainly energy use, are estimated from shortfalls arising from changes to water availability from traditional water sources (mainly storage). These shortfalls are estimated from changes to rainfall and the associated effects on runoff and stream flows (CSIRO and McKeon et al. 2008). The additional water supplied by these alternative supply options is assumed, on average, to use 770 per cent more energy per mega litre than water sourced from traditional water storages. While current energy use by desalination and recycling is much higher than this, it is assumed that these supply options will become more energy efficient through time.

3.4 Port Infrastructure and Operations

Impacts of climate change on port infrastructure and operations include the following:

- Productivity loss (i.e. port downtime) resulting from extreme climatic events (particularly offshore cyclones), ocean swell, extreme wind and increased temperature
- Increase in capital expenditure from changes in design, improvements in protection and damage repairs
- Operational expenditure from additional maintenance and repair costs due to increased damage from extreme climatic events (eg. cyclones), ocean swell, extreme wind and increased temperature.

Productivity losses are modelled as losses in all factor primary productivity reflecting the likelihood that increased downtimes will require an increase in infrastructure to cope with increased activity when ports are open.

Increases in capital and operational expenditures are modelled as increases in capital, equipment, construction services and labour imputs for a given level of port activity.

Assumptions and limitations

The methodologies used to model the impacts of climate change on critical infrastructure is subject to a number of key limitations:

- The sheer number of impacts on infrastructure meant that it was not possible to estimate all impacts in the time available to the Review. For example, while transport infrastucture such as roads and bridges is likely to be significantly affected by climate change, the impacts have not been included in the modelling. For this reason the impacts on critical infrastructure are most likely an underestimate of the impacts from climate change

- Critical infrastructure is likely to be senstive to some impacts that the climate science is uncertain about. For example, much of Australia's infrastructure is close to the coast and hence subject to impacts from sea level rises. The Review has taken a conservative view on sea level rise (0.59 m rise over the century) given the assumed temperature changes that have been modelled. It is possible that actual sea level rises under the temperature changes considered by the Review would be significantly higher than this
- While the infrastructure impacts have been estimated using a range of expertise from both industry and the science community, no formal modelling approach has been used.

4 Health

Climate change is likely to significantly affect the health of Australians over the next century. Some of the main health risks include impacts of temperature extremes (including heat waves), vector-borne infectious diseases (such as dengue virus) and food-borne infectious diseases (such as bacterial gastroenteritis). These health conditions have been analysed and incorporated in the Review's modelling of the direct impacts of climate change.

The climate change health impacts analysed by the Review were estimated by The National Centre for Epidemiology and Population Health (NCEPH) at The Australian National University (ANU) and the School of Medicine, University of Western Sydney (hereafter NCEPH). NCEPH focused their study on three major health conditions:

- Bacterial gastroenteritis
- Dengue virus
- Heat related mortality and hospitalisations.

In incorporating the findings of NCEPH into the modelling, the Review focused on the likely impacts to health expenditure and labour supply in the Australian economy. The Review separately considered the impact extreme temperatures will have on labour productivity in directly affected industries (see section 4.4).

4.1 Projections

The modelling of the health expenditure and labour supply impacts were based on the NCEPH projections of the annual number of cases of gastroenteritis, dengue fever and heat stress. Tables 5 - 7 present a summary of these projections.

Table 5 Projected number of bacterial gastroenteritis cases ('000s)

	Median no-mitigation case			Extreme dry no-mitigation case			Stong mitigation to 550 ppm			Ambitious mitigation to 450 ppm		
	Number of gastroenteritis cases ('000s)											
State	2020	2050	2100	2020	2050	2100	2020	2050	2100	2020	2050	2100
NSW	2512	2923	3306	2516	2941	3350	2514	2910	3183	2518	2902	3159
VIC	1872	2185	2457	1875	2196	2483	1874	2178	2381	1876	2173	2366
QLD	1672	2334	2698	1676	2355	2744	1674	2318	2554	1679	2308	2525
SA	531	528	591	531	531	599	531	526	574	532	525	570
WA	808	1046	1174	809	1050	1185	808	1043	1142	809	1041	1136
TAS	165	151	168	165	152	170	165	151	164	165	150	163
NT	82	118	136	82	119	138	82	117	128	82	117	127
ACT	119	134	152	119	135	153	119	134	146	119	133	145

Source: Bambrick et al. 2008

Table 6 Projected number of people at risk from dengue virus('000s)

	Median no-mitigation case			Extreme dry no-mitigation case			Stong mitigation to 550 ppm			Ambitious mitigation to 450 ppm		
	Number of dengue fever cases ('000s)											
State	2020	2050	2100	2020	2050	2100	2020	2050	2100	2020	2050	2100
NSW	-	-	-	-	-	-	-	-	-	-	-	-
VIC	-	-	-	-	-	-	-	-	-	-	-	-
QLD	333	433	5212	333	433	4710	333	433	473	333	433	473
SA	-	-	-	-	-	-	-	-	-	-	-	-
WA	0	0	61	-	-	-	-	-	-	-	-	-
TAS	-	-	-	-	-	-	-	-	-	-	-	-
NT	147	229	249	147	229	249	147	229	249	147	229	249
ACT	-	-	-	-	-	-	-	-	-	-	-	-

Source: Bambrick et al. 2008

Table 7 Projected number of hospitalisations for heat stress[5]

	Median no-mitigation case			Extreme dry no-mitigation case			Stong mitigation to 550 ppm			Ambitious mitigation to 450 ppm		
	Number of hospitalisations from heat stress											
State	2020	2050	2100	2020	2050	2100	2020	2050	2100	2020	2050	2100
NSW	8925	11547	13027	8933	11575	13161	8926	11527	12841	8934	11525	12816
VIC	8537	11188	12510	8536	11189	12575	8536	11191	12433	8539	11188	12433
QLD	6828	10574	11850	6819	10569	11932	6826	10576	11789	6820	10588	11794
SA	2061	2278	2545	2060	2279	2561	2061	2277	2519	2060	2276	2517
WA	2851	4233	4796	2853	4247	4848	2851	4225	4709	2852	4220	4695
TAS	828	847	934	827	850	936	828	848	940	827	850	938
NT	245	387	433	245	389	438	245	386	426	245	386	424
ACT	387	494	546	387	494	555	387	492	544	387	492	545

Source: Bambrick et al. 2008

The methodology used by NCEPH to derive these projections is detailed in the report on the Review's website (see Bambrick et al. 2008).

4.2 Health expenditure

The expenditure estimates derived by NCEPH are comprised of:

- Direct costs incurred by the health-care system (eg. diagnosis, treatment and care)
- Costs incurred for public health surveillance, prevention and control activities.

Total expenditure projections were derived by estimating a constant cost per case and applying this to the original projections of the annual number of cases (as presented above). The costs incurred from one case of gastroenteritis and one case of heat stress were estimated to be $276.01 and $3410 respectively. For every person at risk of exposure to dengue fever, the cost was estimated to be $2.82.The Review imposed the increased health expenditure in MMRF through a primary factor productivity shock to health services.

4.3 Labour supply

NCEPH also provided estimates for the average number of days a person would have away from work if suffering from gastroenteritis, dengue fever or heat stress. Similar to the total expenditure projections, the labour supply impacts were derived by estimating a constant number of days off work per case. This was then applied to the original projections of the annual number of cases (as presented above). Whilst it was estimated that people with subclinical dengue fever symptoms take approximately two days off work, people with clinical dengue fever symptoms are expected to take approximately ten days off work. The number of days off work from one case of gastroenteritis was estimated to be 2.8.

The Review imposed these impacts as a national decline in labour productivity. It was assumed that the impact on labour supply will be spread equally across all industries.

The effect on labour supply and productivity for cases of heat stress are discussed below.

4.4 Labour productivity under extreme temperatures

With rising temperatures and the increased incidence of heat waves under climate change, it is likely that labour productivity in some industries will be significantly affected. Whilst NCEPH did not provide quantitative analysis of such labour productivity effects, the Review has independently made some assumptions based on a range of published and unpublished material (Brake & Bates 2002; Kjellstrom et al. 2008, various occupational health guidelines) and expert advice[6].

It was assumed that for most industries, a range of cooling options would be available such that labour productivity would be largely unaffected. However, where labour is employed in areas that are exposed to the elements, such as in construction, these options would be difficult or expensive to apply. The Review assumed that labour productivity is most likely to be adversely affected in four key industries in MMRF:

- Construction
- Mining
- Agriculture
- Manufacturing.

In quantifying the effects on these industries, the Review assumed that a worker will experience an average 15 per cent reduction in productivity on days where the temperature exceeds 32 degrees Celsius and an average 30 per cent reduction in productivity on days where the temperature exceeds 35 degrees Celsius. Tables 8 - 10 contain a summary of the estimates used by the Review for the approximate number of days in a year when the temperature exceeds 32 and 35 degrees Celsius under the various climate scenarios.

Table 8 Summary of the estimated number of days per year when temperature exceeds 32 and 35 degrees Celsius resulting from unmitigated climate change scenario.

State	Temperature (°C)	2020	2050	2100
NSW	32-35	4	7	25
	> 35	10	18	83
VIC	32-35	11	17	34
	> 35	23	31	56
QLD	32-35	1	5	47
	> 35	13	38	154
SA	32-35	22	31	57
	> 35	40	54	86
WA	32-35	34	48	91
	> 35	61	83	134
TAS	32-35	2	2	4
	> 35	4	6	11
NT	32-35	31	151	345
	> 35	262	334	364
ACT	32-35	8	16	44
	> 35	23	37	80

Source: CSIRO

Table 9 Summary of the estimated number of days per year when temperature exceeds 32 and 35 degrees Celsius resulting from mitigation to 550 ppm by 2100.

State	Temperature (°C)	2020	2050	2100
NSW	32-35	4	6	8
	> 35	10	16	19
VIC	32-35	11	15	18
	> 35	24	29	32
QLD	32-35	2	4	5
	> 35	13	31	41
SA	32-35	22	29	31
	> 35	41	50	54
WA	32-35	34	45	50
	> 35	62	77	85
TAS	32-35	2	2	2
	> 35	4	5	6
NT	32-35	32	117	163
	> 35	262	323	337
ACT	32-35	8	14	17
	> 35	24	33	38

Source: CSIRO

Table 10 Summary of the estimated number of days per year when temperature exceeds 32 and 35 degrees Celsius resulting from mitigation to 450 ppm by 2100.

State	Temperature (°C)	2020	2050	2100
NSW	32-35	5	6	6
	> 35	11	14	15
VIC	32-35	12	15	15
	> 35	24	28	29
QLD	32-35	2	3	4
	> 35	15	27	29
SA	32-35	23	27	28
	> 35	42	49	50
WA	32-35	35	43	44
	> 35	63	74	76
TAS	32-35	2	2	2
	> 35	4	5	5
NT	32-35	38	100	108
	> 35	273	316	319
ACT	32-35	9	13	13
	> 35	25	31	33

Source: CSIRO

The proportion of workers assumed to be exposed to the elements differed across the four affected industries. Seventy per cent of construction workers and forty per cent of agriculture workers were assumed to be affected, while only ten per cent and twenty per cent of workers were assumed to be affected for the mining and manufacturing industries, respectively.

Assumptions and limitations

The methodology used to estimate impacts is subject to a number of key assumptions and limitations:

- Most health impacts will impinge unevenly across regions and demographic subgroups. Differences in locations, socioeconomic circumstances, preparedness and infrastructure resources will all be significant but were not considered in great detail in the Review's analysis
- The extent to which future adaptive strategies (such as the incidence of new vaccines or health treatments) might modify the estimated ill-health effects was not considered
- Only a few of the potential health risks Australia will face under climate change have been analysed and incorporated in the modelling. For example, incidences of mosquito transmitted diseases such as Malaria, Murray Valley Encephalitis, Ross River fever and Japanese Encephalitis are likely to increase with higher temperatures. Further, diminished food production and quality will have nutritional consequences and increases in air pollution and changes in the production of aeroallergens could potentially exacerbate respiratory diseases. These likely effects are not included in the modelling
- The non-market effects of climate are also likely to have significant implications for Australians. These effects were not considered as part of the Review's modelling.

5 Tropical Cyclones

Increased intensity of tropical cyclone activity is anticipated under climate change. The hazard from tropical cyclones was estimated by Geoscience Australia. In their analysis, Geoscience estimated maximum potential tropical cyclone intensity (MPI) from climatological information in areas where reliable atmospheric soundings exist and data on cyclone intensity was available.

In their MPI estimation, Geoscience used an ensemble of general circulation models that had been integrated for the Intergovernmental Panel of Climate Change (IPCC) Fourth Assessment Report. A summary of the models are provided in Table 11.

Table 11 The models used by Geoscience in their analysis and the corresponding number of simulations.

Model name	Climate change scenarios			
	C2OC	SRES B1	SRES A1B	SRES A2
BCCR BCM 2.0	1	1		1
CCCMA CGCM 3.1	5	5	5	5
CCCMA CGCM 3.1 T63	1	1	1	
CNRM CM 3	1	1	1	1
CSIRO MK 3.0	2	1	1	1
CSIRO MK3.5	1	1	1	1
GFDL CM 2.0	3	1	1	1
GFDL CM 2.1	3	1	1	1
GISS AOM	2	2		
GISS E-H	5			
GISS E-R	7	1	4	1
IAP FGOALS 1.0g	3	3	3	
INGV ECHAM 4	1		1	1
INMCM 3.0	1	1	1	1
IPSL CM 4	2	1	1	1
MIROC 3.2 HIRES	1	1	1	
MIROC 3.2 MEDRES	3	3	3	3
MPI ECHAM 5	4	3	4	3
MRI CGCM 2.3.2a	3	5	5	5
NCAR CCSM 3.0	8	9	6	4
NCAR PCM 1	4	1	3	4
UKMO HADCM 3	2	1		1
UKMO HADGEM 1	1		1	1
TOTAL	64	43	44	36

More information on the methodology used by Geoscience can be found in Tonkin et al. (2000).

Since predicting the actual occurrence of individual cyclone events is not possible, cyclone damages are modelled as a series of average annualised damages (Roson et al. (2006) use a similar technique to estimate impacts from extreme events). These annualised losses are estimated for residential dwellings from damages arising from storm surge and wind speed, but exclude flood damage. These estimates are contained in Table 12.

Table 12 Geoscience estimates for total damage to dwellings from cyclone activity ($ million)

Climate scenario	State	2010	2030	2050	2070	2090
No-mitigation	QLD	57.8	116.5	208.7	383.1	678.1
	WA	1.6	2.6	10.1	17.5	32.7
	NT	19.7	62.8	117.9	167.4	271.2
Strong mitigation to 550 ppm	QLD	78.8	118.3	138.9	171.2	180.4
	WA	2.0	1.8	3.3	5.9	8.0
	NT	16.6	28.7	65.0	57.4	94.7
Ambitious mitigation to 450 ppm	QLD	39.5	32.7	89.4	106.2	118.3
	WA	1.9	2.0	2.4	4.1	6.3
	NT	17.3	28.3	39.5	49.9	60.5

The Review incorporated these estimates in the modelling as an increase in the capital requirements of dwellings.

Based on industry advice[7], the Review extrapolated building damages data from Geoscience to estimate the likely damages to household contents.

Assumptions and limitations

- While consideration of a likely increase in the intensity of tropical cyclones in Southern regions has been included, no consideration has been given to the possible southward movement in the genesis of tropical cyclones (Leslie et al. 2007).
- There is a high degree of uncertainty around predictions for cyclone activity once temperatures increase by more than one or two degrees. Since the scenarios used by the Review consider temperatures considerably higher than this, it should be acknowledged that the estimated impacts from cyclones are highly uncertain.

6 International implications

Climate change will have an affect on a global scale and impacts on Australia's trading partners will have implications for the domestic economy. However, since MMRF is a single country model, it cannot independently estimate the domestic implications of economic shocks to Australia's trading partners.

In order to estimate the international implications of climate change, the Australian Bureau of Agriculture and Resource Economics (ABARE) and the Commonwealth Scientific and Industrial Research Organisation (CSIRO) has estimated the economic impacts of climate change across multiple countries in a Global Integrated Assessment Model (GIAM). GIAM is an integrated assessment model jointly developed by ABARE and CSIRO. It provides insights into the potential economic and environmental impacts of climate change as well as adaptation and mitigation responses at the regional and global level. Further details of the GIAM model can be found in Harman et al. (2008).

6.1 Linking GIAM and MMRF

The International modelling in GIAM is used to inform the more detailed domestic model (MMRF) about changes to international trade. The methodology used to link the two models was developed by the Commonwealth Treasury and is loosely based on methodologies developed by the Centre of Policy Studies (for example see Adams et al. 1996).

The models are linked by taking the following information from GIAM and imposing it in MMRF:

- changes in foreign demand schedules for Australian export orientated commodities
- the shifts in world demand for Australian tourism implied by changes in world GDP and changes to world prices for services
- changes to import prices.

Changes to foreign import prices are taken from GIAM and imposed directly in MMRF. Shifts in world demand for Tourism services are estimated from changes in export volumes and prices in GIAM.

The changes in foreign demand for other commodities is estimated by building a demand equation in GIAM that matches the functional form of the MMRF export demand equation. That is:

x4r = BETA * (p4r –natf4p);

where:
x4r = the per cent change in Australian export volumes;
BETA = the price elasticity of foreign demand;
p4r = the per cent change in Austrlian export prices (expressed in foreign dollars); and
natf4p = the per cent change in foreign demand.

Since GIAM does not have an explicit parameter in the form BETA, this must be estimated in the model. The varable natfp is estimated within GIAM and imposed directly in MMRF.

The key results from the GIAM modelling are discussed in detail in a report prepared by ABARE and CSIRO (see Harman et al, 2008) available on the Review's website.

Assumptions and limitations

- Since there is comparatively little detailed and credible information available on the likely sectoral impacts of climate change globally, limited detail can be incorporated into GIAM. Hence the damage function in GIAM used to estimate climate damages has very little sectoral detail and the economic results for the domestic economy are substantially different from those estimated by the Review in MMRF.
- The lack of sectoral detail may introduce an unavoidable level of error into the trade estimates. For example, this lack of sectoral detail makes it difficult to estimate the global effects on agriculture and hence the implications of climate change on global food supply, and the subsequent implications for domestic agriculture.
- Ideally, a number of iterations would have been undertaken to better match the global and domestic modelling. However, in the time available to the Review this was not possible.

7 Summary of shocks

This technical appendix has discussed the translation of the Review's direct impact analysis into the shocks imposed in MMRF. The below tables ummarise the shocks for each impact area.

All shocks are presented as cumulative percent changes from the base year (2005), unless otherwise stated.

Livestock production

Table 13: Shocks to production for the MMRF indsutry *Sheep and Beef Cattle* .

Impact Area	Nature of Change	Direct impact in MMRF	Climate scenario	Year	NSW	VIC	QLD	SA	WA	TAS	NT	ACT
Sheep and Beef Cattle	Changes to CO2, temperature and rainfall change the carrying capacity of land used in livestocking	Change in all primary factor usage*	Median no-mitigation	2020	2.6	2.2	3.6	4.4	3.5	0.9	3.1	-0.2
				2050	8.0	7.0	10.0	14.1	11.2	3.0	9.3	0.8
				2100	17.8	17.0	16.3	33.3	27.6	8.2	18.7	9.2
			Extreme dry no-mitigation	2020	8.9	5.3	12.0	12.8	10.7	3.6	10.5	3.0
				2050	27.5	17.1	35.3	38.9	33.4	11.8	31.8	11.9
				2100	62.2	43.2	70.6	82.8	76.8	30.0	69.5	40.4
			Mitigation to 550 ppm	2020	2.9	2.3	4.0	4.8	3.8	1.0	3.5	-0.1
				2050	7.4	5.9	9.9	12.3	10.0	2.8	9.0	0.9
				2100	9.3	7.4	12.1	15.5	12.6	3.6	11.2	1.6
			Mitigation to 450 ppm	2020	3.4	2.7	4.7	5.6	4.4	1.2	4.1	0.0
				2050	6.8	5.2	9.3	11.2	9.1	2.5	8.4	0.9
				2100	7.4	5.6	10.1	12.0	9.9	2.8	9.2	1.1
			Mitigation to 550 ppm under extreme drying	2020	9.6	5.6	13.0	13.8	11.5	3.9	11.4	3.3
				2050	24.0	14.4	31.5	33.7	28.9	10.2	28.1	10.1
				2100	29.7	18.1	38.4	41.4	35.9	12.8	34.7	13.4

** A positive change to all primary factor usage reflects a productivity loss (and vice versa)*

Table 14: Shocks to production in the MMRF industry *Dairy* – impacts on cattle feed requirements.

Impact Area	Nature of Change	Direct impact in MMRF	Climate scenario	Year	NSW	VIC	QLD	SA	WA	TAS	NT	ACT
Dairy (1)	Changes to rainfall change cattle feed requirements	Change of intermediate usage of "Grains"	Median no-mitigation	2020	8.4	11.6	7.8	14.0	13.4	4.6	8.1	9.3
				2050	27.5	38.1	25.5	45.8	44.0	15.2	26.7	30.5
				2100	68.5	94.9	63.5	114.1	109.5	37.9	66.4	76.0
			Extreme dry no-mitigation	2020	33.5	27.4	37.9	43.4	42.0	17.4	37.8	27.2
				2050	109.6	89.6	124.1	142.2	137.5	56.9	123.7	89.2
				2100	272.9	223.3	309.2	354.1	342.4	141.7	308.2	222.1
			Mitigation to 550 ppm	2020	9.0	12.5	8.4	15.1	14.4	5.0	8.8	10.0
				2050	23.1	32.0	21.4	38.6	37.0	12.8	22.4	25.7
				2100	29.0	40.2	26.9	48.4	46.4	16.1	28.1	32.2
			Mitigation to 450 ppm	2020	10.4	14.4	9.6	17.3	16.6	5.8	10.1	11.6
				2050	20.7	28.7	19.2	34.5	33.1	11.5	20.1	23.0
				2100	22.1	30.6	20.5	36.8	35.3	12.2	21.4	24.5
			Mitigation to 550 ppm under extreme drying	2020	36.0	29.4	40.8	46.7	45.2	18.7	40.6	29.3
				2050	92.2	75.4	104.4	119.6	115.7	47.9	104.1	75.0
				2100	115.6	94.6	131.0	150.0	145.1	60.0	130.6	94.1

Table 15: Shocks to production in the MMRF industry *Dairy* – productivity impacts due to rainfall change.

Impact Area	Nature of Change	Direct impact in MMRF	Climate scenario	Year	NSW	VIC	QLD	SA	WA	TAS	NT	ACT
Dairy (2)	Changes in rainfall change the productivity of milk producers	Change in all primary factor usage*	Median no-mitigation	2020	4.2	5.8	3.9	7.0	6.7	2.3	4.1	4.7
				2050	13.8	19.0	12.7	22.9	22.0	7.6	13.3	15.3
				2100	34.3	47.4	31.7	57.1	54.7	18.9	33.2	38.0
			Extreme dry no-mitigation	2020	16.7	13.7	19.0	21.7	21.0	8.7	18.9	13.6
				2050	54.8	44.8	62.1	71.1	68.7	28.4	61.9	44.6
				2100	136.4	111.6	154.6	177.0	171.2	70.8	154.1	111.1
			Mitigation to 550 ppm	2020	4.5	6.3	4.2	7.5	7.2	2.5	4.4	5.0
				2050	11.6	16.0	10.7	19.3	18.5	6.4	11.2	12.8
				2100	14.5	20.1	13.4	24.2	23.2	8.0	14.1	16.1
			Mitigation to 450 ppm	2020	5.2	7.2	4.8	8.7	8.3	2.9	5.0	5.8
				2050	10.4	14.3	9.6	17.2	16.5	5.7	10.0	11.5
				2100	11.0	15.3	10.2	18.4	17.6	6.1	10.7	12.3
			Mitigation to 550 ppm under extreme drying	2020	18.0	14.7	20.4	23.3	22.6	9.3	20.3	14.6
				2050	46.1	37.7	52.2	59.8	57.8	23.9	52.1	37.5
				2100	57.8	47.3	65.5	75.0	72.6	30.0	65.3	47.1

** A positive change to all primary factor usage reflects a productivity loss (and vice versa)*

Table 16: Shocks to production in the MMRF industry *Dairy* – productivity Impacts due to temperature change.

Impact Area	Nature of Change	Direct impact in MMRF	Climate scenario	Year	NSW	VIC	QLD	SA	WA	TAS	NT	ACT
Dairy (3)	Heat stress results in lower milk production in dairy cows	Change in all primary factor usage*	Median no-mitigation	2020	0.9	0.8	0.9	0.9	1.0	0.6	1.0	0.8
				2050	3.0	2.5	3.1	2.9	3.3	1.9	3.3	2.7
				2100	7.4	6.2	7.7	7.3	8.2	4.7	8.2	6.8
			Extreme dry no-mitigation	2020	1.1	0.9	1.2	1.1	1.2	0.7	1.2	1.0
				2050	3.7	3.1	3.8	3.6	4.0	2.4	4.0	3.3
				2100	9.2	7.6	9.5	9.1	9.9	5.9	9.9	8.2
			Mitigation to 550 ppm	2020	1.0	0.8	1.0	1.0	1.1	0.6	1.1	0.9
				2050	2.5	2.1	2.6	2.5	2.8	1.6	2.8	2.3
				2100	3.1	2.6	3.3	3.1	3.5	2.0	3.5	2.9
			Mitigation to 450 ppm	2020	1.1	0.9	1.2	1.1	1.2	0.7	1.2	1.0
				2050	2.2	1.9	2.3	2.2	2.5	1.4	2.5	2.1
				2100	2.4	2.0	2.5	2.4	2.6	1.5	2.6	2.2
			Mitigation to 550 ppm under extreme drying	2020	1.2	1.0	1.3	1.2	1.3	0.8	1.3	1.1
				2050	3.1	2.6	3.2	3.1	3.3	2.0	3.3	2.8
				2100	3.9	3.2	4.0	3.8	4.2	2.5	4.2	3.5

** A positive change to all primary factor usage reflects a productivity loss (and vice versa)*

Dry-land grains production

Table 17: Shocks to MMRF for dry-land grains production in the MMRF industry *Grains*.

Impact Area	Nature of Change	Direct impact in MMRF	Climate scenario	Year	NSW	VIC	QLD	SA	WA	TAS	NT	ACT
Dry-land grains production	Changes to CO2, temperature and rainfall change the yield of barley, oats and wheat	Change in all primary factor usage*	Median no-mitigation	2020	-5.7	-10.1	-1.0	-0.5	-9.8	-	-	-
				2050	-11.3	-11.5	-1.2	3.7	-14.2	-	-	-
				2100	-0.4	20.0	2.4	20.2	1.1	-	-	-
			Extreme dry no-mitigation	2020	-1.3	-1.8	0.4	7.7	-7.2	-	-	-
				2050	8.5	19.3	4.0	29.8	0.9	-	-	-
				2100	60.6	83.1	14.7	69.4	47.4	-	-	-
			Mitigation to 550 ppm	2020	-5.3	-9.0	-0.8	0.8	-9.2	-	-	-
				2050	-6.7	-4.7	-0.2	9.0	-9.4	-	-	-
				2100	-6.6	-1.2	0.1	12.9	-7.9	-	-	-
			Mitigation to 450 ppm	2020	-4.9	-7.6	-0.6	2.6	-8.7	-	-	-
				2050	-4.8	-2.5	0.2	10.6	-7.5	-	-	-
				2100	-3.8	0.3	0.5	13.3	-5.9	-	-	-
			Mitigation to 550 ppm under extreme drying	2020	-0.4	0.0	0.7	9.6	-6.3	-	-	-
				2050	8.9	20.5	4.1	31.2	2.2	-	-	-
				2100	14.8	31.5	5.7	40.3	8.5	-	-	-

** A positive change to all primary factor usage reflects a productivity loss (and vice versa)*

Irrigated agriculture

Table 18: Shocks to MMRF for irrigated agriculture production for the MMRF industry *Grains*.

Impact Area	Nature of Change	Direct impact in MMRF	Climate scenario	Year	NSW	VIC	QLD	SA	WA	TAS	NT	ACT
Irrigated cropping (proportion of "Grains" industry)	Changes to runoff change the value of production of irrigated crops ("Grains" includes sugar cane, cotton etc)	Change in all primary factor usage*	Median no-mitigation	2020	2.6	3.4	2.7	4.4	2.1	-	-	-
				2050	12.3	15.8	12.8	20.1	9.3	-	-	-
				2100	47.3	60.4	49.5	75.2	36.2	-	-	-
			Extreme dry no-mitigation	2020	9.7	8.4	11.1	9.6	9.8	-	-	-
				2050	43.4	38.2	49.4	43.2	43.6	-	-	-
				2100	161.2	100.0	178.9	155.1	149.6	-	-	-
			Mitigation to 550 ppm	2020	0.7	0.0	1.8	2.5E-04	2.8E-03	-	-	-
				2050	3.5	0.0	9.7	1.3E-03	1.5E-02	-	-	-
				2100	6.4	0.1	17.5	2.4E-03	2.8E-02	-	-	-
			Mitigation to 450 ppm	2020	0.7	0.0	1.8	2.5E-04	2.8E-03	-	-	-
				2050	3.7	0.0	10.3	1.4E-03	1.6E-02	-	-	-
				2100	5.1	0.1	14.1	1.9E-03	2.2E-02	-	-	-
			Mitigation to 550 ppm under extreme drying	2020	-2.4	0.0	-7.1	-6.0E-04	-0.02	-	-	-
				2050	-12.5	-0.1	-36.6	-3.1E-03	-0.11	-	-	-
				2100	-21.4	-0.2	-61.0	-5.3E-03	-0.15	-	-	-

** A positive change to all primary factor usage reflects a productivity loss (and vice versa)*

Table 19: Shocks to MMRF for irrigated agriculture production for the MMRF industry *Other Agriculture* industry.

Impact Area	Nature of Change	Direct impact in MMRF	Climate scenario	Year	NSW	VIC	QLD	SA	WA	TAS	NT	ACT
Irrigated cropping (proportion of "OtherAg" industry)	Changes to runoff change the value of production of irrigated crops ("OtherAg" includes fruit, nuts, vegetables etc)	Change in all primary factor usage*	Median no-mitigation	2020	2.5	3.4	2.2	4.5	5.7	1.5	-	-
				2050	11.9	16.0	10.4	20.5	25.7	6.9	-	-
				2100	45.9	60.9	40.6	76.4	80.0	27.2	-	-
			Extreme dry no-mitigation	2020	9.3	8.6	9.7	10.1	12.1	4.9	-	-
				2050	42.0	38.6	43.6	45.2	53.4	22.8	-	-
				2100	161.4	152.6	165.8	168.3	207.5	86.5	-	-
			Mitigation to 550 ppm	2020	2.5	3.2	2.1	4.3	5.3	1.4	-	-
				2050	13.0	17.6	11.5	22.6	28.3	7.5	-	-
				2100	23.5	31.6	20.8	40.3	49.9	13.8	-	-
			Mitigation to 450 ppm	2020	2.5	3.2	2.1	4.3	5.3	1.4	-	-
				2050	13.8	18.7	12.2	23.9	30.0	8.1	-	-
				2100	18.9	25.5	16.7	32.7	40.5	11.1	-	-
			Mitigation to 550 ppm under extreme drying	2020	13.4	8.1	9.8	9.2	13.4	5.1	-	-
				2050	49.0	42.3	50.6	47.6	66.9	26.8	-	-
				2100	81.0	73.3	85.5	82.2	97.8	46.7	-	-

** A positive change to all primary factor usage reflects a productivity loss (and vice versa)*

Critical Infrastructure

Table 20: Shocks to MMRF for <u>coastal settlements</u> – capital expenditure changes for new and existing buildings.

Impact Area	Nature of Change	Direct impact in MMRF	Climate scenario	Year	NSW	VIC	QLD	SA	WA	TAS	NT	ACT
Coastal settlements (1)	Capital expenditure on new and existing buildings	Change in capital augmenting technical change	Median no-mitigation	2020	0.8	0.5	0.8	0.8	0.8	0.5	0.9	-
				2050	2.1	1.2	2.2	2.2	2.2	1.2	2.4	-
				2100	4.2	2.4	4.5	4.4	4.4	2.4	4.8	-
			Extreme dry no-mitigation	2020	0.8	0.5	0.8	0.8	0.8	0.5	0.9	-
				2050	2.1	1.2	2.2	2.2	2.2	1.2	2.4	-
				2100	4.2	2.4	4.5	4.4	4.4	2.4	4.8	-
			Mitigation to 550 ppm	2020	0.8	0.5	0.8	0.8	0.8	0.5	0.9	0.0
				2050	2.1	1.2	2.2	2.2	2.2	1.2	2.4	0.0
				2100	2.8	1.6	3.0	2.9	2.9	1.6	3.2	0.0
			Mitigation to 450 ppm	2020	0.8	0.5	0.8	0.8	0.8	0.5	0.9	0.0
				2050	2.1	1.2	2.2	2.2	2.2	1.2	2.4	0.0
				2100	2.8	1.6	3.0	2.9	2.9	1.6	3.2	0.0
			Mitigation to 550 ppm under extreme drying	2020	0.8	0.5	0.8	0.8	0.8	0.5	0.9	0.0
				2050	2.1	1.2	2.2	2.2	2.2	1.2	2.4	0.0
				2100	2.8	1.6	3.0	2.9	2.9	1.6	3.2	0.0

Table 21: Shocks to MMRF for coastal settlements – capital expenditure due to reduced life expectancy of buildings.

Impact Area	Nature of Change	Direct impact in MMRF	Climate scenario	Year	NSW	VIC	QLD	SA	WA	TAS	NT	ACT
Coastal settlements (2)	Capital expenditure for reduced life expectancy of buildings	Change in capital augmenting technical change	Median no-mitigation	2020	1.1	1.1	1.1	1.1	1.1	1.1	1.1	-
				2050	2.0	2.0	2.0	2.0	2.0	1.7	2.0	-
				2100	3.0	4.0	3.0	4.0	4.0	2.0	3.0	-
			Extreme dry no-mitigation	2020	1.1	1.1	1.1	1.1	1.1	1.1	1.1	-
				2050	2.2	2.2	2.2	2.2	2.2	2.0	2.2	-
				2100	5.0	5.0	5.0	5.0	5.0	4.0	5.0	-
			Mitigation to 550 ppm	2020	1.1	1.1	1.1	1.1	1.1	1.1	1.1	0.0
				2050	1.5	1.5	1.5	1.5	1.5	1.3	1.5	0.0
				2100	1.2	1.6	1.2	1.6	1.6	0.8	1.2	0.0
			Mitigation to 450 ppm	2020	1.1	1.1	1.1	1.1	1.1	1.1	1.1	0.0
				2050	1.5	1.5	1.5	1.5	1.5	1.3	1.5	0.0
				2100	0.7	1.0	0.7	1.0	1.0	0.5	0.7	0.0
			Mitigation to 550 ppm under extreme drying	2020	1.1	1.1	1.1	1.1	1.1	1.1	1.1	0.0
				2050	1.6	1.6	1.6	1.6	1.6	1.6	1.6	0.0
				2100	2.0	2.0	2.0	2.0	2.0	1.5	2.0	0.0

Table 22: Shocks to MMRF for coastal settlements – operational expenditure.

Impact Area	Nature of Change	Direct impact in MMRF	Climate scenario	Year	NSW	VIC	QLD	SA	WA	TAS	NT	ACT
Coastal settlements (3)	Operational expenditure from additional maintenance and repair costs	Change in intermediate input technical change	Median no-mitigation	2020	5.0	5.0	5.0	3.3	2.2	2.2	2.2	-
				2050	9.5	9.0	14.4	8.0	6.0	5.5	6.0	-
				2100	14.0	13.0	25.0	14.0	13.0	9.0	13.0	-
			Extreme dry no-mitigation	2020	5.0	5.0	5.0	3.3	2.2	2.2	2.2	-
				2050	10.0	9.5	15.3	8.5	6.5	5.5	6.5	-
				2100	16.0	15.0	28.0	16.0	15.0	11.0	15.0	-
			Mitigation to 550 ppm	2020	5.0	5.0	5.0	3.3	2.2	2.2	2.2	0.0
				2050	8.0	8.0	8.5	6.5	4.5	4.0	4.5	0.0
				2100	5.0	5.0	6.0	5.0	4.0	3.0	4.0	0.0
			Mitigation to 450 ppm	2020	5.0	5.0	5.0	3.3	2.2	2.2	2.2	0.0
				2050	7.5	7.5	8.0	6.0	4.0	3.5	4.0	0.0
				2100	4.0	4.0	5.0	4.0	3.0	2.0	3.0	0.0
			Mitigation to 550 ppm under extreme drying	2020	5.0	5.0	5.0	3.9	2.8	2.2	2.8	0.0
				2050	8.5	8.5	9.5	7.5	5.5	4.5	5.5	0.0
				2100	7.0	7.0	8.0	7.0	5.0	3.0	5.0	0.0

Table 23: Shocks to the MMRF industry *Electricity Supply* for impacts to <u>electricity transmission and distribution</u> - capital expenditure.

Impact Area	Nature of Change	Direct impact in MMRF	Climate scenario	Year	NSW	VIC	QLD	SA	WA	TAS	NT	ACT
Electricity transmission and distribution	Capital expenditure from additional changes in design and early renewal/ replacement of infrastructure	Change in capital augmenting technical change	Median no-mitigation	2020	2.2	2.2	2.8	2.2	1.1	1.7	1.1	1.7
				2050	7.9	7.4	11.8	7.9	9.2	3.0	8.8	3.5
				2100	16.0	14.0	26.0	15.0	23.0	8.0	20.0	7.0
			Extreme dry no-mitigation	2020	2.2	2.2	2.8	2.2	1.1	1.7	1.1	1.7
				2050	8.9	8.4	12.7	8.9	10.2	3.5	9.7	4.5
				2100	18.0	16.0	28.0	17.0	25.0	10.0	22.0	9.0
			Mitigation to 550 ppm	2020	2.2	2.2	2.8	2.2	1.1	1.7	1.1	1.7
				2050	6.0	5.5	7.5	6.0	5.4	2.5	5.4	3.0
				2100	5.0	4.0	7.0	5.0	4.0	1.0	4.0	2.0
			Mitigation to 450 ppm	2020	2.2	2.2	2.8	2.2	1.1	1.7	1.1	1.7
				2050	5.0	4.5	7.0	5.0	4.5	2.0	4.5	2.5
				2100	4.0	3.0	7.0	4.0	5.0	0.0	5.0	1.0
			Mitigation to 550 ppm under extreme drying	2020	2.2	2.2	2.8	2.2	1.1	1.7	1.1	1.7
				2050	6.5	6.5	8.9	6.5	5.9	3.0	5.9	3.5
				2100	7.0	7.0	10.0	7.0	8.0	4.0	8.0	5.0

Table 24: Shocks to MMRF industry *Electricity Supply* for impacts to <u>electricity transmission and distribution</u> - operational expenditure.

Impact Area	Nature of Change	Direct impact in MMRF	Climate scenario	Year	NSW	VIC	QLD	SA	WA	TAS	NT	ACT
Electricity transmission and distribution	Operational expenditure from additional maintenance and repair costs	Change in intermediate input technical change	Median no-mitigation	2020	4.4	4.4	5.0	4.4	2.2	2.8	2.2	2.8
				2050	8.0	7.5	10.5	8.0	6.5	5.0	7.0	4.5
				2100	13.0	13.0	24.0	13.0	21.0	10.0	18.0	9.0
			Extreme dry no-mitigation	2020	4.4	4.4	5.0	4.4	2.2	2.8	2.2	2.8
				2050	9.0	8.5	11.5	9.0	7.4	6.0	7.9	5.5
				2100	15.0	15.0	26.0	15.0	23.0	12.0	20.0	11.0
			Mitigation to 550 ppm	2020	4.4	4.4	5.0	4.4	2.2	2.8	2.2	2.8
				2050	7.0	7.0	7.5	7.0	4.5	3.5	4.5	4.0
				2100	4.0	4.0	4.0	4.0	4.0	1.0	4.0	2.0
			Mitigation to 450 ppm	2020	4.4	4.4	5.0	4.4	2.2	2.8	2.2	2.8
				2050	6.5	6.5	7.0	6.5	4.0	3.0	4.0	3.5
				2100	3.0	3.0	3.0	3.0	3.0	0.0	3.0	1.0
			Mitigation to 550 ppm under extreme drying	2020	5.0	5.0	5.0	5.0	2.8	2.8	2.8	3.3
				2050	8.0	8.0	8.0	8.0	6.0	4.0	6.0	5.0
				2100	5.0	5.0	5.0	5.0	5.0	2.0	5.0	3.0

Table 25: Shocks to the MMRF industry *Water Supply* – capital expenditure for alternative water supply infrastructure.

Impact Area	Nature of Change	Direct impact in MMRF	Climate scenario	Year	NSW	VIC	QLD	SA	WA	TAS	NT	ACT
Water Supply (1)	Capital expenditure - additional capital costs to provide alternative water supply (eg. desalination plants)	Change in capital augmenting technical change	Median no-mitigation	2020	6.6	7.2	6.6	8.8	10.3	0.0	0.6	2.8
				2050	15.0	16.4	15.0	19.9	22.9	1.5	3.5	8.0
				2100	19.0	25.0	19.0	28.0	34.0	4.0	11.0	17.0
			Extreme dry no-mitigation	2020	8.2	8.2	8.2	9.8	10.9	0.0	1.1	4.4
				2050	18.4	18.9	18.4	21.9	24.4	4.4	6.9	11.4
				2100	24.0	28.0	24.0	32.0	37.0	18.0	21.0	22.0
			Mitigation to 550 ppm	2020	6.6	7.2	6.6	8.8	10.3	0.0	0.6	2.8
				2050	11.0	12.0	11.0	15.5	17.5	0.0	0.5	4.5
				2100	3.0	3.0	3.0	4.0	5.0	0.0	0.0	1.0
			Mitigation to 450 ppm	2020	6.6	7.2	6.6	8.8	10.3	0.0	0.0	2.8
				2050	10.5	11.0	10.0	14.0	16.5	0.0	0.0	4.0
				2100	2.0	3.0	2.0	3.0	4.0	0.0	0.0	1.0
			Mitigation to 550 ppm under extreme drying	2020	8.2	8.2	8.2	9.8	10.9	0.0	1.1	4.4
				2050	15.5	15.5	16.5	18.0	22.5	1.0	3.0	11.9
				2100	7.0	7.0	9.0	9.0	16.0	1.0	2.0	7.0

Table 26: Shocks to the MMRF industry *Water Supply* – capital expenditure for replacement of existing distribution infrastructure.

Impact Area	Nature of Change	Direct impact in MMRF	Climate scenario	Year	NSW	VIC	QLD	SA	WA	TAS	NT	ACT
Water Supply (2)	Capital expenditure - additional costs related to water supply distribution infrastructure	Change in capital augmenting technical change	Median no-mitigation	2020	1.7	1.7	1.7	2.2	2.2	0.0	0.0	1.1
				2050	3.5	3.5	3.5	4.0	4.5	0.5	1.0	2.5
				2100	4.0	4.0	4.0	5.0	5.0	2.0	3.0	4.0
			Extreme dry no-mitigation	2020	1.7	1.7	1.7	2.2	2.2	0.0	0.0	1.1
				2050	3.5	3.5	3.5	4.5	4.5	1.5	1.5	2.5
				2100	4.0	5.0	4.0	5.0	5.0	4.0	4.0	4.0
			Mitigation to 550 ppm	2020	1.7	1.7	1.7	2.2	2.2	0.0	0.0	1.1
				2050	3.0	3.0	3.0	3.5	4.0	0.0	0.0	1.5
				2100	1.0	2.0	1.0	2.0	2.0	0.0	0.0	1.0
			Mitigation to 450 ppm	2020	1.7	1.7	1.7	2.2	2.2	0.0	0.0	1.1
				2050	2.0	2.5	2.5	3.0	3.0	0.0	0.0	1.5
				2100	1.0	1.0	1.0	2.0	2.0	0.0	0.0	1.0
			Mitigation to 550 ppm under extreme drying	2020	1.7	1.7	1.7	2.2	2.2	0.0	0.0	1.1
				2050	3.0	3.0	3.5	4.0	4.0	0.5	1.0	2.5
				2100	2.0	2.0	3.0	3.0	3.0	0.0	1.0	2.0

Table 27: Shocks to the MMRF industry *Water Supply*– operational expenditure.

Impact Area	Nature of Change	Direct impact in MMRF	Climate scenario	Year	NSW	VIC	QLD	SA	WA	TAS	NT	ACT
Water Supply (3)	Operational expenditure from additional maintenance and repair costs	Change in intermediate input technical change	Median no-mitigation	2020	3.3	5.0	3.3	5.0	5.5	0.0	1.1	2.2
				2050	4.5	7.5	5.0	7.5	8.5	1.0	2.0	3.5
				2100	4.0	7.0	5.0	7.0	8.0	2.0	2.0	4.0
			Extreme dry no-mitigation	2020	3.9	5.5	3.9	5.5	5.5	0.0	2.2	2.8
				2050	6.0	8.5	6.5	8.5	9.0	1.5	3.5	5.0
				2100	6.0	8.0	7.0	8.0	8.0	4.0	4.0	5.0
			Mitigation to 550 ppm	2020	3.3	5.0	3.3	5.0	5.5	0.0	1.1	2.2
				2050	4.5	7.0	4.5	7.0	8.0	0.0	2.0	3.5
				2100	2.0	4.0	2.0	5.0	5.0	0.0	1.0	2.0
			Mitigation to 450 ppm	2020	3.3	5.0	3.3	5.0	5.5	0.0	1.1	2.2
				2050	4.0	6.5	4.0	6.5	7.5	0.0	2.0	3.0
				2100	2.0	3.0	2.0	4.0	4.0	0.0	1.0	2.0
			Mitigation to 550 ppm under extreme drying	2020	3.9	5.5	3.9	5.5	5.5	0.0	2.2	2.8
				2050	5.0	7.5	5.5	7.5	8.0	1.0	3.0	4.0
				2100	2.0	4.0	3.0	4.0	5.0	2.0	2.0	2.0

Table 28: Shocks to the MMRF industry *Water Supply* – use of electricity

Impact Area	Nature of Change	Direct impact in MMRF	Climate scenario	Year	NSW	VIC	QLD	SA	WA	TAS	NT	ACT
Water Supply (4)	Electricity Usage by Water Supply industry	Change in intermediate input technical change	Median no-mitigation	2020	14.0	19.3	12.0	26.0	39.3	0.0	-0.7	15.3
				2050	66.0	91.3	58.0	122.0	182.0	0.7	-3.3	73.3
				2100	170.0	233.3	152.0	302.0	425.3	1.3	-9.3	190.0
			Extreme dry no-mitigation	2020	47.3	40.0	48.7	56.0	72.7	23.3	27.3	46.0
				2050	195.3	166.7	202.7	228.0	287.3	99.3	116.0	191.3
				2100	430.7	382.0	452.7	484.0	563.3	239.3	284.0	426.0
			Mitigation to 550 ppm	2020	15.3	21.3	13.3	29.3	44.0	0.0	-0.7	17.3
				2050	53.3	74.7	47.3	100.7	150.0	0.7	-2.7	60.7
				2100	69.3	96.0	61.3	129.3	191.3	0.7	-3.3	78.0
			Mitigation to 450 ppm	2020	18.7	26.0	16.7	36.0	54.7	0.0	-0.7	22.0
				2050	46.7	65.3	41.3	88.7	132.7	0.7	-2.0	53.3
				2100	50.7	70.7	44.7	95.3	142.7	0.7	-2.7	57.3
			Mitigation to 550 ppm under extreme drying	2020	52.0	43.3	53.3	61.3	79.3	25.3	30.0	50.0
				2050	174.7	148.7	181.3	204.0	258.0	88.7	103.3	170.7
				2100	222.0	190.7	231.3	258.0	322.0	114.0	134.0	217.3

Table 29: Shocks to the MMRF industry *Water Transport* – productivity impacts from port downtime.

Direct impact in MMRF	Climate scenario	Year	NSW	VIC	QLD	SA	WA	TAS	NT	ACT
Change in capital augmenting technical change	Median no-mitigation	2020	0.2	0.2	0.3	0.2	0.3	0.2	0.2	-
		2050	0.5	0.5	1.0	0.5	0.9	0.5	0.6	-
		2100	0.9	0.9	1.9	0.9	1.8	0.9	1.6	-
	Extreme dry no-mitigation	2020	0.2	0.2	0.3	0.2	0.3	0.2	0.2	-
		2050	0.5	0.5	1.0	0.5	0.9	0.5	0.6	-
		2100	0.9	0.9	1.9	0.9	1.8	0.9	1.6	-
	Mitigation to 550 ppm	2020	0.2	0.2	0.3	0.2	0.3	0.2	0.2	-
		2050	0.5	0.5	0.6	0.5	0.6	0.4	0.5	-
		2100	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-
	Mitigation to 450 ppm	2020	0.2	0.2	0.3	0.2	0.3	0.2	0.2	-
		2050	0.4	0.4	0.5	0.4	0.5	0.4	0.4	-
		2100	0.4	0.4	0.5	0.4	0.5	0.4	0.4	-
	Mitigation to 550 ppm under extreme drying	2020	0.2	0.2	0.3	0.2	0.3	0.2	0.2	-
		2050	0.5	0.5	0.6	0.5	0.6	0.5	0.5	-
		2100	0.5	0.5	0.7	0.5	0.7	0.5	0.5	-

Table 30: Shocks to the MMRF indsutry *Water Transport* – capital expenditure for ports.

Direct impact in MMRF	Climate scenario	Year	NSW	VIC	QLD	SA	WA	TAS	NT	ACT
Change in intermediate input technical change	Median no-mitigation	2020	0.2	0.2	0.2	0.1	0.2	0.1	0.1	-
		2050	0.8	0.7	0.9	0.4	0.8	0.4	0.4	-
		2100	1.3	1.1	1.7	0.7	1.5	0.7	1.0	-
	Extreme dry no-mitigation	2020	0.2	0.2	0.2	0.1	0.2	0.1	0.1	-
		2050	0.8	0.7	0.9	0.4	0.8	0.4	0.5	-
		2100	1.5	1.3	1.9	0.9	1.8	0.9	1.3	-
	Mitigation to 550 ppm	2020	0.2	0.2	0.2	0.1	0.2	0.1	0.1	-
		2050	0.6	0.5	0.6	0.2	0.6	0.3	0.3	-
		2100	0.6	0.4	0.7	0.2	0.7	0.1	0.2	-
	Mitigation to 450 ppm	2020	0.2	0.2	0.2	0.1	0.2	0.1	0.1	-
		2050	0.5	0.5	0.5	0.2	0.5	0.2	0.2	-
		2100	0.4	0.3	0.5	0.1	0.5	0.1	0.1	-
	Mitigation to 550 ppm under extreme drying	2020	0.2	0.2	0.2	0.1	0.2	0.1	0.1	-
		2050	0.7	0.6	0.7	0.3	0.7	0.3	0.4	-
		2100	0.8	0.6	0.9	0.3	0.9	0.3	0.4	-

Table 31: Shocks to the MMRF industry *Water Transport* – operational expenditure for ports.

Impact Area	Nature of Change	Direct impact in MMRF	Climate scenario	Year	NSW	VIC	QLD	SA	WA	TAS	NT	ACT
Ports (3)	Operational expenditure form additional maintenance and repair costs	Change in intermediate input technical change	Median no-mitigation	2020	0.3	0.3	0.3	0.2	0.3	0.2	0.2	-
				2050	0.7	0.7	0.8	0.5	0.7	0.5	0.5	-
				2100	0.8	0.8	1.1	0.6	1.0	0.6	0.9	-
			Extreme dry no-mitigation	2020	0.3	0.3	0.3	0.2	0.3	0.2	0.2	-
				2050	0.7	0.7	0.8	0.5	0.7	0.5	0.5	-
				2100	0.9	0.9	1.4	0.7	1.3	0.7	1.1	-
			Mitigation to 550 ppm	2020	0.3	0.3	0.3	0.2	0.3	0.2	0.2	-
				2050	0.6	0.6	0.6	0.4	0.6	0.4	0.4	-
				2100	0.5	0.5	0.5	0.3	0.5	0.2	0.3	-
			Mitigation to 450 ppm	2020	0.3	0.3	0.3	0.2	0.3	0.2	0.2	-
				2050	0.6	0.6	0.6	0.4	0.6	0.4	0.4	-
				2100	0.4	0.4	0.4	0.2	0.4	0.2	0.2	-
			Mitigation to 550 ppm under extreme drying	2020	0.3	0.3	0.3	0.2	0.3	0.2	0.2	-
				2050	0.7	0.7	0.7	0.5	0.7	0.5	0.5	-
				2100	0.6	0.6	0.6	0.4	0.6	0.4	0.4	-

Health

Table 32: Shocks to the MMRF industry *Public Services* – expenditure due to incidence of dengue fever ($ million)

Impact Area	Illness	Direct impact in MMRF	Climate scenario	Year	NSW	VIC	QLD	SA	WA	TAS	NT	ACT
Health - Expenditure ($ million)	Dengue Fever	Change in primary factor usage	Median no-mitigation	2020	-	-	0.9	-	0.0	-	0.4	-
				2050	-	-	1.2	-	0.0	-	0.6	-
				2100	-	-	14.7	-	0.2	-	0.7	-
			Extreme dry no-mitigation	2020	-	-	0.9	-	-	-	0.4	-
				2050	-	-	1.2	-	-	-	0.6	-
				2100	-	-	13.3	-	-	-	0.7	-
			Mitigation to 550 ppm	2020	-	-	0.9	-	-	-	0.4	-
				2050	-	-	1.2	-	-	-	0.6	-
				2100	-	-	1.3	-	-	-	0.7	-
			Mitigation to 450 ppm	2020	-	-	0.9	-	-	-	0.4	-
				2050	-	-	1.2	-	-	-	0.6	-
				2100	-	-	1.3	-	-	-	0.7	-
			Mitigation to 550 ppm under extreme	2020	-	-	0.9	-	-	-	0.4	-
				2050	-	-	1.2	-	-	-	0.6	-
				2100	-	-	1.3	-	-	-	0.7	-

Table 33: Shocks to the MMRF industry *Public Services* – expenditure due to incidence of gastroenteritis ($ million).

Impact Area	Illness	Direct impact in MMRF	Climate scenario	Year	NSW	VIC	QLD	SA	WA	TAS	NT	ACT
Health - Expenditure ($ million)	Gastro-enteritis	Change in primary factor usage	Median no-mitigation	2020	572.3	421.1	319.8	132.8	165.1	41.6	17.1	28.0
				2050	584.4	428.2	330.5	134.9	167.5	42.1	17.7	28.6
				2100	608.4	442.7	350.4	139.2	172.5	43.3	18.8	29.8
			Extreme dry no-mitigation	2020	573.1	421.5	320.6	133.0	165.2	41.6	17.1	0.0
				2050	587.9	430.2	333.5	135.7	168.2	42.3	17.9	0.0
				2100	616.4	447.3	356.4	141.1	174.2	43.7	19.1	0.0
			Mitigation to 550 ppm	2020	688.7	513.1	455.2	146.1	220.4	45.4	22.3	32.6
				2050	801.1	599.6	635.1	145.6	286.2	41.9	32.1	36.8
				2100	877.5	656.3	704.1	158.1	314.8	45.2	35.4	40.2
			Mitigation to 450 ppm	2020	689.6	513.7	456.3	146.3	220.6	45.5	22.3	32.7
				2050	799.1	598.3	632.6	145.3	285.7	41.8	32.0	36.8
				2100	871.0	652.4	696.0	157.3	313.1	45.0	35.0	39.9
			Mitigation to 550 ppm under extreme	2020	689.9	513.8	456.5	146.4	220.7	45.5	22.3	32.7
				2050	805.2	601.9	640.1	146.3	287.2	42.0	32.3	37.0
				2100	883.3	659.6	711.0	159.2	316.2	45.4	35.7	40.5

Table 34: Shocks to the MMRF industry *Public Services* – health expenditure due to incidence of heat stress ($ million)

Impact Area	Illness	Direct impact in MMRF	Climate scenario	Year	NSW	VIC	QLD	SA	WA	TAS	NT	ACT
Health - Expenditure ($ million)	Heat Stress	Change in primary factor usage	Median no-mitigation	2020	30.0	28.7	22.8	7.0	9.5	2.8	0.8	1.3
				2050	39.2	38.0	35.7	7.8	14.3	2.9	1.3	1.7
				2100	44.4	42.6	40.3	8.7	16.3	3.2	1.5	1.9
			Extreme dry no-mitigation	2020	30.0	28.7	22.7	7.0	9.5	2.8	0.8	1.3
				2050	39.3	38.0	35.7	7.8	14.4	2.9	1.3	1.7
				2100	44.8	42.8	40.6	8.7	16.5	3.2	1.5	1.9
			Mitigation to 550 ppm	2020	30.0	28.7	22.8	7.0	9.5	2.8	0.8	1.3
				2050	39.2	38.0	35.8	7.8	14.3	2.9	1.3	1.7
				2100	43.7	42.3	40.1	8.6	16.0	3.2	1.4	1.9
			Mitigation to 450 ppm	2020	30.0	28.7	22.7	7.0	9.5	2.8	0.8	1.3
				2050	39.1	38.0	35.8	7.8	14.3	2.9	1.3	1.7
				2100	43.7	42.4	40.2	8.6	16.0	3.2	1.4	1.9
			Mitigation to 550 ppm under extreme	2020	30.0	28.7	22.7	7.0	9.5	2.8	0.8	1.3
				2050	39.2	38.0	35.7	7.8	14.3	2.9	1.3	1.7
				2100	43.8	42.4	40.1	8.6	16.1	3.2	1.5	1.9

Table 35: Health impacts – shocks to labour supply resulting from dengue fever (working days lost)

Impact Area	Illness	Direct impact in MMRF	Climate scenario	Year	NSW	VIC	QLD	SA	WA	TAS	NT	ACT
Health - Working days lost	Dengue Fever	Change in effective labour supply	Median no-mitigation	2020	-	-	1665	-	0	-	735	-
				2050	-	-	2166	-	0	-	1147	-
				2100	-	-	26061	-	306	-	1244	-
			Extreme dry no-mitigation	2020	-	-	1665	-	-	-	735	-
				2050	-	-	2166	-	-	-	1147	-
				2100	-	-	23551	-	-	-	1244	-
			Mitigation to 550 ppm	2020	-	-	1665	-	-	-	735	-
				2050	-	-	2166	-	-	-	1147	-
				2100	-	-	2365	-	-	-	1244	-
			Mitigation to 450 ppm	2020	-	-	1665	-	-	-	735	-
				2050	-	-	2166	-	-	-	1147	-
				2100	-	-	2365	-	-	-	1244	-
			Mitigation to 550 ppm under extreme	2020	-	-	1665	-	-	-	735	-
				2050	-	-	2166	-	-	-	1147	-
				2100	-	-	2365	-	-	-	1244	-

Table 36: Health impacts – shocks to labour supply resulting from gastroenteritis (working days lost).

Impact Area	Illness	Direct impact in MMRF	Climate scenario	Year	NSW	VIC	QLD	SA	WA	TAS	NT	ACT
Health - Working days lost ('000s)	Gastro-enteritis	Change in effective labour supply	Median no-mitigation	2020	5808	4273	3247	1347	1675	422	174	285
				2050	5934	4347	3358	1369	1701	428	180	291
				2100	6176	4493	3557	1413	1751	439	191	303
			Extreme dry no-mitigation	2020	5817	4278	3255	1349	1677	422	174	285
				2050	5971	4368	3389	1378	1708	429	182	292
				2100	6257	4541	3619	1432	1768	443	194	306
			Mitigation to 550 ppm	2020	7040	5247	4689	1487	2264	461	229	333
				2050	8147	6097	6490	1473	2919	422	329	374
				2100	8913	6666	7151	1606	3197	459	359	408
			Mitigation to 450 ppm	2020	7052	5254	4700	1489	2266	462	230	334
				2050	8125	6084	6463	1470	2914	421	328	373
				2100	8846	6626	7069	1597	3180	457	355	405
			Mitigation to 550 ppm under extreme	2020	7053	5255	4702	1490	2266	462	230	334
				2050	8190	6122	6542	1480	2930	424	332	376
				2100	8971	6700	7222	1617	3211	461	363	411

Table 37: Health impacts – shocks to labour supply resulting from heat stress (working days lost).

Impact Area	Illness	Direct impact in MMRF	Climate scenario	Year	NSW	VIC	QLD	SA	WA	TAS	NT	ACT
Health - Working days lost	Heat Stress	Change in effective labour supply	Median no-mitigation	2020	12681	12129	9701	2928	4051	1176	348	550
				2050	16406	15896	15024	3237	6014	1203	550	702
				2100	18509	17774	16836	3616	6814	1327	615	776
			Extreme dry no-mitigation	2020	12692	12128	9688	2927	4054	1175	348	550
				2050	16446	15897	15016	3238	6034	1208	553	702
				2100	18699	17867	16953	3639	6888	1330	622	789
			Mitigation to 550 ppm	2020	12682	12128	9698	2928	4051	1176	348	550
				2050	16378	15900	15026	3235	6003	1205	548	699
				2100	18244	17665	16750	3579	6691	1336	605	773
			Mitigation to 450 ppm	2020	12693	12132	9690	2927	4052	1175	348	550
				2050	16375	15896	15043	3234	5996	1208	548	699
				2100	18209	17665	16757	3576	6671	1333	602	774
			Mitigation to 550 ppm under extreme	2020	12693	12127	9688	2928	4054	1174	348	548
				2050	16420	15897	15024	3241	6016	1203	553	702
				2100	18293	17673	16737	3580	6712	1338	607	773

Table 38: Health impacts from changes in temperature and increased incidence of heat waves – shocks to labour productivity in the MMRF industry *Construction*.

Impact Area	Nature of Change	Direct impact in MMRF	Climate scenario	Year	NSW	VIC	QLD	SA	WA	TAS	NT	ACT
"Construction" industry	Impact of rising temperatures and increased incidence of heat waves	Change in labour productivity	No-mitigation	2020	0.02	0.04	0.01	0.09	0.11	0.00	0.44	0.06
				2050	0.11	0.22	0.12	0.35	0.53	0.02	3.92	0.30
				2100	0.67	0.72	1.40	1.11	1.77	0.09	9.48	1.13
			Mitigation to 550 ppm	2020	0.02	0.04	0.01	0.11	0.12	0.00	0.47	0.06
				2050	0.08	0.16	0.09	0.30	0.43	0.01	2.92	0.23
				2100	0.12	0.24	0.13	0.37	0.57	0.02	4.27	0.32
			Mitigation to 450 ppm	2020	0.02	0.05	0.02	0.13	0.14	0.01	0.63	0.07
				2050	0.07	0.15	0.07	0.26	0.36	0.01	2.43	0.20
				2100	0.07	0.16	0.08	0.28	0.40	0.01	2.67	0.22

Table 39: Health impacts from changes in temperature and increased incidence of heat waves – shocks to labour productivity in MMRF's *Agriculture* industries.

Impact Area	Nature of Change	Direct impact in MMRF	Climate scenario	Year	NSW	VIC	QLD	SA	WA	TAS	NT	ACT
"Mining" industry	Impact of rising temperatures and increased incidence of heat waves	Change in labour productivity	No-mitigation	2020	0.00	0.01	0.00	0.01	0.02	0.00	0.06	0.01
				2050	0.02	0.03	0.02	0.05	0.08	0.00	0.56	0.04
				2100	0.10	0.10	0.20	0.16	0.25	0.01	1.36	0.16
			Mitigation to 550 ppm	2020	0.00	0.01	0.00	0.02	0.02	0.00	0.07	0.01
				2050	0.01	0.02	0.01	0.04	0.06	0.00	0.42	0.03
				2100	0.02	0.03	0.02	0.05	0.08	0.00	0.61	0.05
			Mitigation to 450 ppm	2020	0.00	0.01	0.00	0.02	0.02	0.00	0.09	0.01
				2050	0.01	0.02	0.01	0.04	0.05	0.00	0.35	0.03
				2100	0.01	0.02	0.01	0.04	0.06	0.00	0.38	0.03

Table 40: Health impacts from changes in temperature and increased incidence of heat waves – shocks to labour productivity in MMRF's *Mining* industries.

Impact Area	Nature of Change	Direct impact in MMRF	Climate scenario	Year	NSW	VIC	QLD	SA	WA	TAS	NT	ACT
"Agriculture" industry	Impact of rising temperatures and increased incidence of heat waves	Change in labour productivity	No-mitigation	2020	0.01	0.02	0.01	0.05	0.07	0.00	0.25	0.03
				2050	0.06	0.13	0.07	0.20	0.31	0.01	2.25	0.17
				2100	0.38	0.41	0.80	0.64	1.01	0.05	5.44	0.65
			Mitigation to 550 ppm	2020	0.01	0.03	0.01	0.06	0.07	0.00	0.27	0.03
				2050	0.05	0.09	0.05	0.17	0.25	0.01	1.68	0.13
				2100	0.07	0.14	0.07	0.21	0.33	0.01	2.44	0.18
			Mitigation to 450 ppm	2020	0.01	0.03	0.01	0.07	0.08	0.00	0.36	0.04
				2050	0.04	0.09	0.04	0.15	0.21	0.01	1.39	0.12
				2100	0.04	0.09	0.05	0.16	0.23	0.01	1.53	0.12

Table 41: Health impacts from changes in temperature and increased incidence of heat waves – shocks to labour productivity in MMRF's *Manufacturing* industries.

Impact Area	Nature of Change	Direct impact in MMRF	Climate scenario	Year	NSW	VIC	QLD	SA	WA	TAS	NT	ACT
"Manufacturing" industry	Impact of rising temperatures and increased incidence of heat waves	Change in labour productivity	No-mitigation	2020	0.01	0.01	0.00	0.03	0.03	0.00	0.13	0.02
				2050	0.03	0.06	0.03	0.10	0.15	0.01	1.13	0.08
				2100	0.19	0.21	0.40	0.32	0.51	0.03	2.72	0.32
			Mitigation to 550 ppm	2020	0.01	0.01	0.00	0.03	0.03	0.00	0.13	0.02
				2050	0.02	0.05	0.03	0.09	0.12	0.00	0.84	0.07
				2100	0.03	0.07	0.04	0.11	0.16	0.01	1.22	0.09
			Mitigation to 450 ppm	2020	0.01	0.02	0.01	0.04	0.04	0.00	0.18	0.02
				2050	0.02	0.04	0.02	0.07	0.10	0.00	0.70	0.06
				2100	0.02	0.04	0.02	0.08	0.11	0.00	0.77	0.06

Cyclones

Table 42: Cyclone impacts – increased capital expenditure arising from average annual capital stock loss ($ million).

Impact Area	Nature of Change	Direct impact in MMRF	Climate scenario	Year	NSW	VIC	QLD	SA	WA	TAS	NT	ACT
Cyclones	Damage to dwellings ($ million)	Change in capital augmenting technical change	No-mitigation	2020	-	-	43.3	-	1.2	-	14.7	-
				2050	-	-	139.5	-	4.5	-	76.6	-
				2100	-	-	604.4	-	28.9	-	245.3	-
			Mitigation to 550 ppm	2020	-	-	59.1	-	1.5	-	12.4	-
				2050	-	-	123.5	-	2.2	-	37.7	-
				2100	-	-	178.1	-	7.5	-	85.4	-
			Mitigation to 450 ppm	2020	-	-	29.6	-	1.4	-	12.9	-
				2050	-	-	46.9	-	2.1	-	31.1	-
				2100	-	-	115.3	-	5.7	-	57.8	-

Table 43: Cyclone impacts – damage to house and contents ($ million).

Impact Area	Nature of Change	Direct impact in MMRF	Climate scenario	Year	NSW	VIC	QLD	SA	WA	TAS	NT	ACT
Cyclones	Damage to house and contents ($ million)	Change in capital augmenting technical change	No-mitigation	2020	-	-	43.3	-	1.2	-	14.7	-
				2050	-	-	139.5	-	4.5	-	76.6	-
				2100	-	-	604.4	-	28.9	-	245.3	-
			Mitigation to 550 ppm	2020	-	-	59.1	-	1.5	-	12.4	-
				2050	-	-	123.5	-	2.2	-	37.7	-
				2100	-	-	178.1	-	7.5	-	85.4	-
			Mitigation to 450 ppm	2020	-	-	29.6	-	1.4	-	12.9	-
				2050	-	-	46.9	-	2.1	-	31.1	-
				2100	-	-	115.3	-	5.7	-	57.8	-

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[1] Steve Crimp, Craig Miller, CSRIO.

[2] The QCCCE has estimated changes to runoff, by statistical division, from the CSIRO estimates of rainfall change using a methodology outlined in Zhang L, Dawes WR, Walker GR (2001) "Response of mean annual evapotranspiration to vegetation changes at a catchment scale", *Water Resources Research*, **37(3)** pp. 701-708.

[3] The statistical division shares of irrigated land was calculated from data contained in Australian Bureau of Statistics, 2004, *AgStats on GSP* (7117.0.30.001), Canberra.

[4] Quiggin et al.(2008) RSMG; Carter, QCCCE.

[5] These projections are a combination of increased hospitalisations resulting from extreme heat and declines in cold-related illness.

[6] Tjord Kjellstrom, Australian National University

[7] Mark Laplastrier, Natural Hazards Research. Insurance Australia Group.