North East Greenhouse Alliance

Historical climate, climate change and water availability

Water in North East Victoria - Socioeconomic adaptation planning

- Falls Creek Alpine Resort
- Mount Buller / Mount Stirling Alpine Resort
- Mount Hotham Alpine Resort
- Benalla Rural City
- Mansfield Shire Council

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EXECUTIVE SUMMARY

North East Greenhouse Alliance (NEGHA) has identified the necessity to develop a regional climate change adaptation strategy for its region of influence. Under the Strengthening the Basin Communities component of the Water for the Future programme, the Australian Government has funded the 'Water in North East Victoria – Socioeconomic adaptation planning' project proposed by the NEGHA. The objective of the project is to develop a strategy to manage climate change impacts and resulting vulnerabilities, with some additional focus on water variability issues. It is envisaged that developing adaptive actions to mitigate the risks and building resilience within communities will enable the region to better respond to future climatic conditions and impacts. Specifically this study reviewed and analysed historical climate, climate change and water availability within parts of the Goulburn Broken and North East CMA regions. A methodology developed by DPI was used to interpolate climate scenarios generated by CSIRO to daily climate sequences for each of the climate stations within the study area. These daily climate sequences were incorporated into existing surface water and groundwater models to assess the major impacts of climate change on water availability projections to 2030 and 2070. The modelling approach adopted in this study used a suite of physically based farming system models and a fully distributed multi-layered groundwater model and is shown to offer fine scale, CMA wide regional estimates across a range of designated future climate scenarios.

Specific conclusions from this study are:

1. Data analysis suggests that LGAs located in the snowfields would expect minor reductions in rainfall and notable increases in average daily temperature, these increases in temperature are likely to reduce to duration and depth of snow in these locations. Mt Buller, Mt Stirling, Mt Hotham and Falls Creek are most likely to observe the greatest to least increase in temperature respectively under climate change.
2. The greatest falls in groundwater level and storage were identified to occur in the Mansfield Shire, which is likely to be attributed to the majority of the LGA being located upon basement geology and native vegetation cover.
3. Large uncertainties are associated with climate change predictions, both at the point scale and catchment scale. These uncertainties are introduced due to variability in the underpinning data, simulation model constructs and assumptions adopted with model applications.
4. Significant variations in climate change impacts on water availability have been previously reported, and in some cases contrast the predictions derived in this study. This reinforces the degree of uncertainties associated with the derivation of the hydrological impact of future climate scenarios.
5. Under the low 2030 climate condition runoff would be reduced by between 2% and 16% depending upon landscape position and dynamics. In order of increasing impact, Mount Hotham Alpine Resort would be least impacted (-2%) followed by Falls Creek Alpine Resort (-2%), then Mount Stirling Alpine Resort (-4%), Rural City of Benalla (-4%), Shire of Mansfield (-8%) and Mount Buller Alpine Resort (-16%).

6. Under the dry extreme 2030 climate condition runoff would be reduced by between 10% and 35% across the LGAs. In order of increasing impact, Mount Hotham Alpine Resort would be least impacted (-10%) followed by Falls Creek Alpine Resort (-11%), Rural City of Benalla (-20%), Mount Stirling Alpine Resort (-23%), Shire of Mansfield (-25%) and Mount Buller Alpine Resort (-35%).
7. Under the low 2070 climate condition flows would be reduced to approximately those predicted under the dry extreme 2030 climate conditions with reductions ranging between 10% and 35%.
8. Under the dry extreme 2070 climate condition flows would be reduced across the LGAs by between 34% and 72%. In order of increasing impact, Mount Hotham Alpine Resort would be least impacted (-34%) followed by Falls Creek Alpine Resort (-37%), Mount Stirling Alpine Resort (-39%), Rural City of Benalla (-67%), Shire of Mansfield (-71%) and Mount Buller Alpine Resort (-72%)
9. An understanding of landscape dynamics is critical in estimating the impact of climate change on water availability, productivity and groundwater sustainability.

On the basis that the IPCC original climate change projections have been revised, this study recommends undertaking more detailed modelling using the recently updated CCAM Mark 3.6 pattern of change data from CSIRO. Enhancement of the existing groundwater model to better capture temporal groundwater dynamics and sustainable extraction limits has also been identified as a key recommendation.

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1 INTRODUCTION AND AIMS

North East Greenhouse Alliance (NEGHA) has identified the necessity to develop a regional climate change adaptation strategy for its region of influence. Under the Strengthening the Basin Communities component of the Water for the Future programme, the Australian Government has funded the 'Water in North East Victoria – Socioeconomic adaptation planning' project proposed by the NEGHA. The objective of the project is to develop a strategy to manage climate change impacts and resulting vulnerabilities, with some additional focus on water variability issues. It is envisaged that developing adaptive actions to mitigate the risks and building resilience within communities will enable the region to better respond to future climatic conditions and impacts.

Information provided within this report specifically describes the following local government areas (Figure 1);

- Benalla Rural City
- Mansfield Shire Council
- Mt Buller & Mt Stirling Alpine Resort
- Mt Hotham Alpine Resort
- Falls Creek Alpine Resort

This report follows-on from a previous report prepared by Beverly & Hocking (2010) who described climate change characteristics of the following areas;

- Alpine Shire Council
- Towong Shire Council
- Indigo Shire Council
- Rural City of Wangaratta
- City of Wodonga

The aim of this initial phase of the project is to establish the context in terms of climate and water availability scenarios and projections. The project will review the predicted climatic variability and associated water security issues across the Goulburn Broken and North East. It is expected that the project findings will inform the –Climate change vulnerability assessment and resilience planning element of the project.

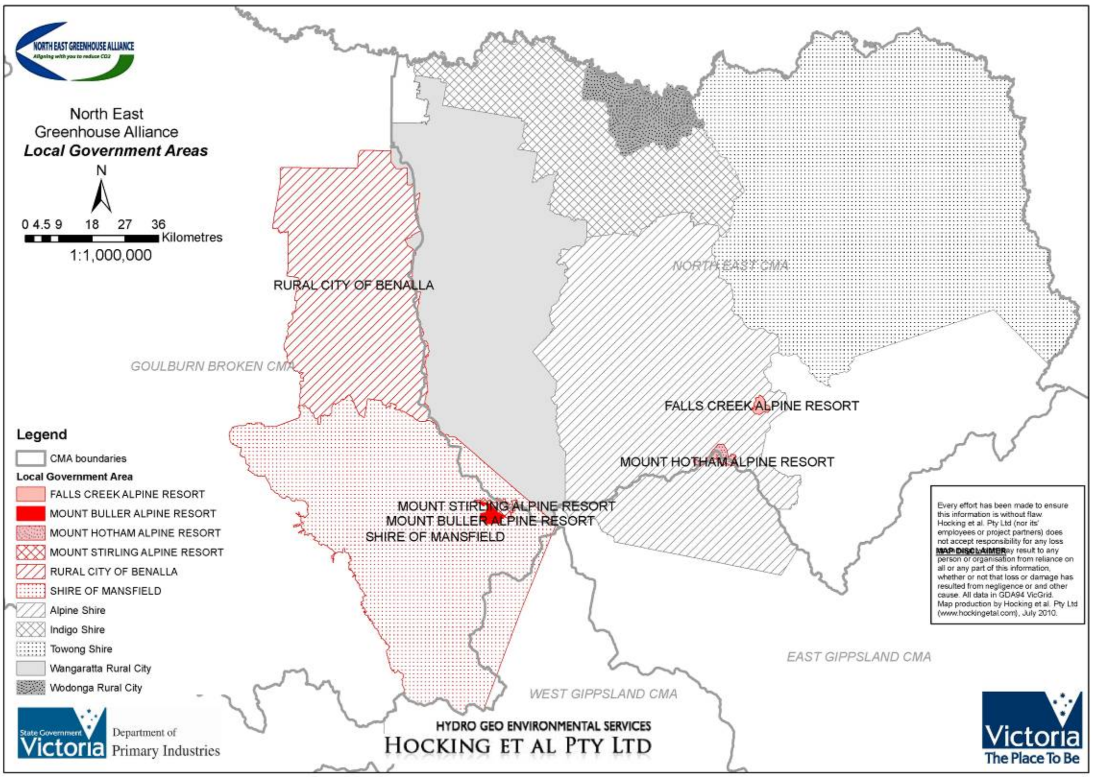


Figure 1 Location of focus local government areas (shaded red)

Study objectives

The objective of this study is to develop an understanding of the water availability and water security in the pre mentioned regions and the capacity of the region (and its constituents) to respond to adverse climate change impacts. Specifically, the consultancy will aim to review and analyse historical climate, climate change and water availability;

This study will review and analyse historical climate, climate change and water availability for the pre mentioned areas relating to:

1. all relevant published information related to climate change induced water stress;
2. developing an understanding of climate variability and attending impacts;
3. establish four climate change scenarios incorporating emission levels, rainfall and temperature variations;
4. provide a method for assessing the major impacts of climate change on water availability projections to 2030 and 2070;
5. evaluate the four climate change scenarios developed in (3);
6. provide selected information in the given format;
7. provide an electronic version of the data used as well as the source data;
8. provide a narrative explanation of key external variables such as environmental commitments, priority of access and seasonal factors (minimum flow expectations) contribute to the water availability in the region; and
9. outline the limitations of data and information available including knowledge gaps.

Methodology

The consultancy collated climate, streamflow and selected groundwater hydrograph data from the relevant custodians including the Bureau of Meteorology, Goulburn-Murray Water, MDBA, DSE, CSIRO and SKM. Numerous surface water and groundwater studies were sourced, as was all streamflow, groundwater hydrograph and spatial data layers within the study area. The recently developed groundwater model of the CSIRO Sustainable Yields modelling reports were used in this review as a reference data set.

Upon collation of the climate data, analysis was undertaken to assess and report climate variability. A methodology has been developed by the project team to interpolate climate scenarios developed by CSIRO to daily climate sequences for each of the climate stations within the study area. These daily climate sequences were incorporated into existing surface water and groundwater models to assess the major impacts of climate change on water availability projections to 2030 and 2070.

Acknowledgements

The authors would like to gratefully acknowledge Brendan Christy and Anna Weeks from the Victorian Department of Primary Industries (DPI), Rutherglen Centre, for assistance in the derivation of the downscaled future climate data sets.

2 PREVIOUS CLIMATE CHANGE STUDIES

This section summarises key findings from previous climate change studies undertaken within the Goulburn Broken CMA region. The specific relevant studies are:

1. IPCC fourth assessment
2. CSIRO Murray Darling basin Sustainable Yields project
3. Water Availability in the Ovens and Goulburn Broken undertaken by CSIRO as part of the Murray-Darling Basin Sustainable Yields project
4. Northern Region Sustainable Water Strategy
5. The Victorian Climate Change Adaptation Program
6. North East Water Water Supply Demand Strategy
7. DSE: Estimating the impacts of climate change on Victoria's runoff.

It is noteworthy that no study was identified that specifically assessed the likely impact of climate change on biodiversity within the specified study areas.

In most cases the previous studies adopted future climate scenarios based on the global warming predictions released by the International Panel of Climate Change (IPCC) in 2001. These global warming predictions were reported in the IPCC Fourth Assessment and are described below as background information.

2.1 IPCC fourth assessment

In 2001 the International Panel of Climate Change (IPCC) released a series of global warming scenarios describing future emissions of greenhouse gases and aerosols based on different socio-economic assumptions. Using the predicted increase in atmospheric concentration of greenhouse gasses the IPCC also generated a series of projected modified global temperatures for each of the various scenarios presented below.

2.1.1 B1 scenario: Low emission growth scenario

The B1 scenario represents the lower emission growth projection and assumes that there is a rapid shift to less fossil-fuel intensive industries. Under this scenario it is assumed that there will be a weak increase in CO_2 emissions until 2040 and thereafter a decline. CO_2 concentrations approximately double by 2100 relative to pre-industrial levels. A global temperature increase of 1.8^{o}C relative to 1990 is predicted with a range from 1.1 to 2.9^{o}C likely.

2.1.2 A1B scenario: Medium emission growth scenario

The A1B scenario represents the medium emissions growth projection and assumes that there is a balanced use of different energy sources. CO_2 emissions are assumed to increase moderately until 2030 and decline by the middle of the 21st century. By 2100 a global temperature increase of 2.8^{o}C relative to 1990 is predicted with a range from 1.7 to 4.4^{o}C likely

2.1.3 A1F1 scenario: High emission growth scenario

The A1F1 scenario represents the high emissions growth projection and assumes a continuation of economic growth based on continued dependence on fossil fuels. CO_2

concentrations are assumed to triple by 2100 relative to pre-industrial levels. Additionally, a global temperature increase of 4.0^{o}C relative to 1990 is predicted with a range from 2.4 to 6.4^{o}C likely. This scenario represents the highest level of late 21st century emissions that were considered to be plausible in 2000. However, recent evidence indicates that CO_2 emissions have been growing at a more rapid rate and that this scenario is now considered the medium projection.

To account for regional impacts of climate change, CSIRO developed the CCAM model which is a global atmosphere-only model that predicts mean-monthly pattern of change per degree of global warming for temperature, rainfall and solar radiation. Two versions of the CCAM model have been developed (Mark 2 and Mark 3) utilising different parameterisations of physical processes. Outputs from each of these models are presented on a 50km x 50km grid and require application of downscaling processes to be relevant at a finer resolution.

2.2 CSIRO Murray Darling Basin Sustainable Yields

In late 2006 CSIRO was commissioned by the then Prime Minister and MDB Premiers to report on the sustainable yields of surface and groundwater systems within the MDB. Eighteen (18) regions were assessed with separate reports prepared for each region. The assessments were framed around four scenarios of climate and development based on the available 111 years of daily climate data. Each of the four scenarios is presented below with associated key findings relevant to the Ovens Catchment, which is the only groundwater management area which extends into the areas of interest.

2.2.1 Scenario A: Historical climate and current development

This scenario represented the baseline condition to be used for comparison with other scenarios and was based on the historical climate from mid-1895 to mid-2006 assuming the current level of water resource development.

2.2.2 Scenario B: Recent climate and current development

This scenario is based on the recent climate sequence recorded for 1997 to 2006. It is used to evaluate the consequence of a long-term continuation of the recent severe drought in south eastern Australia and is assumed to be a reference for the climate change scenarios.

2.2.3 Scenario C: Future climate and current development

This scenario considered climate change at 2030 based on three global warming estimates derived using 15 of the global climate models summarised in the fourth assessment report of the Intergovernmental Panel on Climate Change. The assessments focused on the median of the range with the uncertainty estimates based on the reported 'wet extreme' and 'dry extreme' within the same range.

2.2.4 Scenario D: Future climate and future development

This scenario incorporated the likely future development and the 2030 climate. The future development accounted for growth in farm dam capacity, expansion of commercial forestry plantations and increase in groundwater extractions. It is noteworthy that the projections of future farm dams and commercial forestry plantations were based on 'best guesses' whereas the projections of future groundwater extractions represent maximum allowable use under existing water sharing arrangements.

2.2.5 Key findings

Estimates of the impact of future climate on water resource within the region were only derived for the Ovens catchment, and only for 2030. Tabled below are the predicted effects of climate change by 2030 on water availability within the Ovens catchment Groundwater Management Area (GMA).

Table 1 2030 climate change surface water impacts in the Ovens basin.

Attribute	Units	Historical climate	2030 climate		
			Wet extreme	Median	Dry extreme
Surface water availability	GL/year	1,776	1,802	1,542	974
Total surface water use	GL/year	25	25	25	26
Bulk entitlements @ 100%	GL/year	37.23			
% of years with 100% allocation	%	63	75	63	40
% of years with 50% allocation	%	100	100	100	98
% of years with 0% allocation	%	0	0	0	0

Table 2 CSIRO estimates of groundwater use for the Ovens catchment GMA

2004/05 groundwater use	12.3 GL
2004/05 groundwater use as a percentage of total average water use	33%
2004/05 groundwater use as percentage of total water use in year of lowest surface water use	45%
Possible 2030 groundwater use	23.0 GL
2030 groundwater use as a percentage of total average water use	48%
2030 groundwater use as percentage of total water use in year of lowest surface water use	60%

Table 3 CSIRO estimates of surface water availability for the Ovens catchment GMA

	No development, historical climate	Current development, historical climate	Current development, recent climate
Total inflows	1,970.3	1,970.3	1,462.3
Total losses	194.6	193.3	159.0
Total surface water diversions	-	25.4	25.6
Induced streamflow loss to g/w	-	0.0	0.0
Total end-of-valley surface flow	1,775.7	1,751.6	1,277.7
Average surface water availability	1,775.5	-	1,303.2
Relative level of surface water use	-	1%	2%

Table 4 CSIRO estimates 2030 surface water availability for the Ovens catchment assuming current development.

	Median 2030 climate	Wet extreme 2030 climate	Dry extreme 2030 climate
Total inflows	1,718.1	1,995.0	1,103.7
Total losses	175.1	191.0	130.8
Total surface water diversions	25.4	25.3	26.0
Induced streamflow loss to g/w	0.0	0.0	0.0
Total end-of-valley surface flow	1,517.6	1,778.7	946.9
Average surface water availability	1,542.1	1,802.0	973.8
Relative level of surface water use	2%	1%	3%

Table 5 CSIRO estimates 2030 surface water availability for the Ovens catchment assuming future development.

	Median 2030 climate	Wet extreme 2030 climate	Dry extreme 2030 climate
Total inflows	1,707.4	1,984.3	1,093.1
Total losses	174.6	191.0	130.6
Total surface water diversions	25.3	25.2	25.8
Induced streamflow loss to g/w	0.0	0.0	0.0
Total end-of-valley surface flow	1,507.5	1,768.1	936.7
Average surface water availability	1,542.1	1,802.0	973.8
Relative level of surface water use	2%	1%	3%

2.3 CSIRO Water Availability in the Ovens and Goulburn-Broken Studies

This report described the assessment undertaken for the Ovens region and parts of the Goulburn Broken region as part of the CSIRO Murray-Darling Basin Sustainable Yields Project commissioned in late 2006 by the then Prime Minister and MDB Premiers. The water availability study included rainfall-runoff modelling, river system modelling and groundwater assessment for each of the four climate scenarios adopted in the basin-wide CSIRO Murray-Darling Basin Sustainable Yields Project, namely:

Scenario A	Historical climate and current development:	This scenario represented the baseline condition to be used for comparison with other scenarios and was based on the historical climate from mid-1895 to mid-2006 assuming the current level of water resource development.
Scenario B	Recent climate and current development	This scenario is based on the recent climate sequence recorded for 1997 to 2006. It is used to evaluate the consequence of a long-term continuation of the recent severe drought in south eastern Australia and is assumed to be a reference for the climate change scenarios.
Scenario C	Future climate and current development	This scenario considered climate change at 2030 based on three global warming estimates derived using 15 of the global climate models summarised in the fourth assessment report of the Intergovernmental Panel on Climate Change. The assessments focused on the median of the range with the uncertainty estimates based on the reported ‘wet extreme’ and ‘dry extreme’ within the same range.
Scenario D	Future climate and future development	This scenario incorporated the likely future development and the 2030 climate. The future development accounted for growth in farm dam capacity, expansion of commercial forestry plantations and increase in groundwater extractions. It is noteworthy that the projections of future farm dams and commercial forestry plantations were based on ‘best guesses’ whereas the projections of future groundwater extractions represent maximum allowable use under existing water sharing arrangements.

The rainfall-runoff modelling was based on application of the lumped conceptual daily SIMHYD model. This model was chosen as it is simple and has relatively few parameters (only 6) which are typically derived though optimisation techniques based on matching observed monthly runoff series and daily flow duration characteristics. The rainfall-runoff model was calibrated against 1975 to 2006 streamflow.

The river system assessment was based on REALM modelling with accounting for farm dam impacts, groundwater pumping, storage behaviour, diversions and consumptive water use. This model was recently updated by Sinclair Knight Merz for the Victorian Department of Sustainability and Environment and operates on weekly time steps. The model represents the Ovens river system and includes over 300 links and over 240 nodes arranged into 15 river sections (11 river sections on the King River and 4 river sections on the Buffalo River) and accounts for small tributaries and various supporting water accounting functions.

The groundwater assessment estimated the impacts of climate and development on groundwater management units (GMUs) and was based on groundwater recharge modelling. Rainfall-recharge modelling was undertaken for all GMUs and adopted scaling factors for different soil and land use conditions. These scaling factors were used to scale recharge for given changes in rainfall. In high priority regions, numerical groundwater models were used (refer Section 3.1). However in the Ovens study no numerical groundwater models was used, instead the groundwater response was estimated using the simplified rainfall-recharge approach, a simple water balance analysis and an indicator based on the ratio of extraction to rainfall recharge.

2.3.1 Key findings for the Ovens

The impacts of the 2030 climate change predictions on water balance components are summarised in Table 6 and show that mean annual runoff will vary between a 44% reduction to a 1% increase relative to historic conditions. The corresponding variability in soil evaporation and plant performance (evapotranspiration) is estimated to be an 11% reduction to a 3% increase. This demonstrates the considerable uncertainty in the climate change impact estimates as acknowledged in the Ovens assessment report (CSIROa, 2008). It is also noteworthy that the future development had negligible impact on catchment averaged mean annual runoff and evapotranspiration. Other key findings pertain to the river system modelling which predicted the following:

1. Current average water availability is 1776 GL/year. The current level of use is very low: 25 GL/year (1.4%) is diverted for use including 19 GL/year (1.1%) for irrigation.
2. The main storages in the region are Lake William Hovel and Lake Buffalo. Regulated supply provides for 58% of the total bulk entitlement and licensed volume.
3. The Ovens region uses four levels of water restrictions: levels 1 and 2 are mild restrictions; levels 3 and 4 are severe restrictions. For Wangaratta, mild water restrictions are currently activated in less than 5% of years as are severe restrictions. For Bright, mild water restrictions are currently activated in 37% of years while severe restrictions are activated in 10% of years.
4. If the climate of the last ten years were to persist, water availability and end-of-system flows would be reduced by 27% but average surface water use would be unaffected. However, mild and severe water restrictions would be activated more

frequently for both Wangaratta and Bright due to increases in demand as a result of lower rainfall and high evaporation.

5. Under the best estimate 2030 climate water availability and end-of-system flows would be reduced by 13% with negligible impact on average surface water use. Water supply to Bright would require mild water restrictions in 41% of years and severe restrictions in 14% of years. The frequency of water restrictions for Wangaratta would be largely unaffected.
6. Under the wet extreme 2030 climate water availability would increase slightly, but reduced demand would mean surface water diversions would be slightly lower. Water restrictions for Bright would be activated less frequently. Under the dry extreme 2030 climate water availability would be reduced by 45% and demand would increase due to reduced rainfall and increased evaporation, resulting in a slight increase in average surface water use. End-of-system flows to the Murray River would be reduced by 46%. Water supply to Bright would require mild restrictions in 62% of years and severe restrictions in 21% of years. Water supply to Wangaratta would require mild restrictions in 18% of years and severe restrictions in 14% of years.
7. Projected growth in commercial forestry plantations in the region is negligible, and the projected 8% increase in farm dams would have only minor impact on future runoff.

The key finding from the groundwater assessment is that groundwater can provide a secure water source during drier periods. Whereas groundwater is an important source of water under average flow years, this significance increases under drier future conditions. Table 7 summarises the groundwater extractions as a percentage of total available water (surface and groundwater) for low flow periods under future climate scenarios. However it is noted in the report that these extraction limits are very sensitive to the ratio of extraction to recharge estimates and by definition the recharge estimates which do not explicitly account for spatially explicit land use, land management, soil and catchment location.

Table 6 CSIRO water balance for the Ovens catchment by scenario.

Scenario	Rainfall	Runoff	Evapotranspiration
	mm		
A	1004	231	773
	percentage change from A		
B	-	-26%	-
Cdry	-19%	-44%	-11%
Cmid	-4%	-13%	-2%
Cwet	+3%	+1%	+3%
Ddry	-19%	-44%	-11%
Dmid	-4%	-13%	-2%
Dwet	+3%	+1%	+3%

Table 7 CSIRO estimates of groundwater extractions as a percentage of total available water (surface and groundwater) for low flow periods under future climate scenarios.

	Lowest 1-year period	Lowest 3-year period	Lowest 5-year period	Average
A	45%	40%	39%	33%
B	44%	39%	38%	32%
Cdry	48%	39%	37%	32%
Cmid	45%	39%	39%	33%
Cwet	45%	40%	39%	33%
Dry	64%	55%	53%	47%
Dmid	60%	55%	54%	48%
Dwet	61%	55%	54%	48%

2.4.1 Key findings for the Goulburn Broken

The impacts of the 2030 climate change predictions on water balance components are summarised in Table 8 and show that mean annual runoff will vary between a 44% to a 2% reduction relative to historic conditions. The corresponding variability in soil evaporation and plant performance (evapotranspiration) is estimated to be an 12% reduction to a 1% increase. This demonstrates the considerable uncertainty in the climate change impact estimates as acknowledged in the Goulburn-Broken assessment report (CSIROb, 2008). It is also noteworthy that the future development had negligible impact on catchment averaged mean annual runoff and evapotranspiration. Other key findings pertain to the river system modelling which predicted the following:

1. Current average water availability is 3233 GL/year. The current level of use is 1099 GL/year (34%) is diverted for use including plus an additional 507 GL/year (15%) along the Waranga Channel.
2. If the climate of the last ten years were to persist, water availability and end-of-system flows would be reduced by 41% and the average surface water use would be reduced by 25%. However, mild and severe water restrictions would be activated more frequently for both Wangaratta and Bright due to increases in demand as a result of lower rainfall and high evaporation.
3. Under the best estimate 2030 climate water availability and end-of-system flows would be reduced by 22% with a 14% reduction on average surface water use.
4. Under the wet extreme 2030 climate water availability would decrease by 3%, but reduced demand would mean surface water diversions would be slightly lower..
5. Projected growth in commercial forestry plantations in the region is negligible, and the projected 8% increase in farm dams would have only minor impact (0.5%) on future runoff.

The key finding from the groundwater assessment is that groundwater can provide a secure water source during drier periods. Whereas groundwater is an important source of water under average flow years, this significance increases under drier future conditions. Table 9 summarises the groundwater extractions as a percentage of total available water (surface and groundwater) for low flow periods under future climate scenarios. However it is noted in the report that these extraction limits are very sensitive to the ratio of extraction to recharge estimates and by definition the recharge estimates which do not explicitly account for spatially explicit land use, land management, soil and catchment location.

Table 8 CSIRO water balance for the Ovens catchment by scenario.

Scenario	Rainfall	Runoff	Evapotranspiration
		mm	
A	764	149	614
		percentage change from A	
B	-	-41%	-
Cdry	-19%	-44%	-12%
Cmid	-4%	-13%	-2%
Cwet	0%	-2%	0%
Ddry	-19%	-44%	-12%
Dmid	-4%	-13%	-1%
Dwet	0%	-3%	+1%

Table 9 CSIRO estimates of groundwater extractions as a percentage of total available water (surface and groundwater) for low flow periods under future climate scenarios.

	Lowest 1-year period	Lowest 3-year period	Lowest 5-year period	Average
A	16%	13%	13%	10%
B	53%	24%	22%	14%
Cdry	63%	28%	25%	15%
Cmid	29%	16%	15%	11%
Cwet	19%	14%	13%	11%
Dry	72%	39%	36%	23%
Dmid	41%	24%	23%	17%
Dwet	29%	21%	21%	16%

2.5 Northern Region Sustainable Water Strategy

In 2006 the Victorian Government announced the Our Water Our Future initiative aimed at assessing water availability across Victoria over the next 50 years. The Northern Region Sustainable Water Strategy was subsequently developed. A component of this Strategy was to identify and assess the future threat to water resources in northern Victoria, including the impacts arising from climate change and climate variability. The Strategy adopted the CSIRO's low, medium and high climate change scenarios and a more severe scenario based on a continuation of the extreme conditions experienced sine July 1997. All four scenarios were compared to long-term averages with allowance for predicted population changes, water extraction, regulated rivers, land use changes, bushfires and interception activities such as small farm dams.

2.5.1 Base Case: Long term average based on July 1890 to June 2007

This scenario represented the baseline condition to be used for comparison with other scenarios and was based on the historical climate from mid-1890 to mid-2007 assuming the current level of water resource development.

2.5.2 Scenario A: Based on CSIRO low climate change predictions

This scenario represents the lower emission growth projection and assumes that there is a rapid shift to less fossil-fuel intensive industries. Under this scenario it is assumed that there will be a weak increase in CO_2 emissions until 2040 and thereafter a decline. CO_2 concentrations approximately double by 2100 relative to pre-industrial levels. A global temperature increase of 1.8 ^{o}C relative to 1990 is predicted with a range from 1.1 to 2.9 ^{o}C likely.

2.5.3 Scenario B: Based on CSIRO medium climate change predictions

The medium scenario represents the medium emissions growth projection and assumes that there is a balanced use of different energy sources. CO_2 emissions are assumed to increase moderately until 2030 and decline by the middle of the 21st century. By 2100 a global temperature increase of 2.8^{o}C relative to 1990 is predicted with a range from 1.7 to 4.4^{o}C likely

2.5.4 Scenario C: Based on CSIRO high climate change predictions

This scenario represents the high emissions growth projection and assumes a continuation of economic growth based on continued dependence on fossil fuels. CO_2 concentrations are assumed to triple by 2100 relative to pre-industrial levels. Additionally, a global temperature increase of 4.0^{o}C relative to 1990 is predicted with a range from 2.4 to 6.4^{o}C likely. This scenario represents the highest level of late 21st century emissions that were considered to be plausible in 2000. However, recent evidence indicates that CO_2 emissions have been growing at a more rapid rate and that this scenario is now considered the medium projection.

2.5.6 Scenario D: Based on continuation of recent inflow July 1997 to June 2007

This scenario assumes continuation of inflows based on July 1997 to June 2007 data.

2.5.7 Key findings

The key findings focused on river system inflows. With regards to the region the key river systems considered were the Kiewa and Ovens. The forecast 2055 change in inflows relative to long term averages are summarised in Table 10.

Table 10 Forecast changes in total inflows (compared to long term averages) at 2055

River system	A – Low climate change	B – Medium climate change	C – High climate change	D – Continuation of low inflows
Kiewa	-5%	-19%	-32%	-23%
Ovens	-6%	-24%	-41%	-33%
Murray	+8%	-21% (-1975 GL)	-40%	-43%
Goulburn	-7%	-25% (-829 GL)	-43%	-49%

2.6 The Victorian Climate Change Adaptation Program

In 2008 the Victorian Government initiated a joint departmental strategy involving DPI and DSE to report on the likely impacts of climate change at 2030 and 2070 on water availability, farm and primary production, biodiversity and communities. A series of regional climate change profiles were developed and are available online from www.climatechange.vic.gov.au. These profiles were aimed to providing an overview of the likely impacts and were not intended for impact analysis or developing adaptation responses. The climate change projections underpinning this strategy were collated by CSIRO on behalf of the Victorian Government. The projections were consistent with the Australian climate change projections released in 2007 incorporating results from the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (2007).

The predictions for 2030 were based on the median emission scenario whereas the 2070 projections were based on the lower and higher emission scenarios. For each emission scenario ranges of uncertainty were reported reflecting different results derived from up to 23 global climate models. All results were reported relative to a 30 year period centred on 1990.

2.6.1 Key findings

The key findings from this study relevant to the region pertain to average annual runoff in key river basins (Table 11), future seasonal climate projections (Table 12) and broad climatic variations (Table 13).

Table 11 Variation in average annual runoff in key river basins.

Catchment	2030	2070
Kiewa River	-20%	-5% to -50%
Oven River	-25%	-5% to -50%
Upper Murray	-20%	-5% to -50%
Goulburn River	-35%	-5% to -50%

Table 12 Future seasonal climate projections for the region

	2030	2070
Spring	Warmer by 0.3 to 1.6^{o}C	Warmer by 0.8 to 5.0^{o}C
	Precipitation decrease +3 to -15%	Precipitation decrease +10 to -40%
Summer	Warmer by 0.3 to 2.0^{o}C	Warmer by 0.8 to 6.0^{o}C
	Precipitation change uncertain +15 to -15%	Precipitation change uncertain +40 to -40%
Autumn	Warmer by 0.3 to 1.6^{o}C	Warmer by 0.8 to 5.0^{o}C
	Precipitation change uncertain +10 to -10%	Precipitation change uncertain +25 to -25%
Winter	Warmer by 0.2 to 1.4^{o}C	Warmer by 0.7 to 4.3^{o}C
	Precipitation decrease +3 to -10%	Precipitation decrease +10 to -25%

Table 13 Summary of projected climate changes for the North-East region

Temperature	Annual warming of 0.3 to 1.6oC by 2030 and 0.8 to 5.0oC by 2070
	Day time maximum temperatures and night time minimum temperatures will rise at a similar rate
	Warming will be similar throughout the seasons
	A 10 to 60% in crease in the number of hot days (over 35oC) by 2030 and a 20 to 300% increase by 2070 on the plains. The rate of increase will be greater in the mountains.
	A 0 to 50% reduction in the number of frost days by 2030 and a 50 to 100% decrease by 2070.
Precipitation	Annual precipitation decrease of +3 to -10% by 2030 and +10 to -25% by 2070
	Extreme heavy rainfall events likely to become more intense
Drought	Droughts are likely to become more frequent and longer, particularly in winter-spring
	Dry conditions that currently occur on average one in every five winter-springs may increase up to one in three years by 2030
	Due to hotter conditions droughts are likely to become more intense
Snow	The total alpine area with an average of at least one day of snow cover per year is expected to decrease by 10 to 39% by 2020 and 22 to 85% by 2050. Areas with at least 30 days of snow cover are expected to decrease by 14 to 54% by 2020 and 30 to 93% by 2050. Areas with at least 60 days of snow cover are expected to decrease by 18 to 60% by 2020 and 38 to 96% by 2050.
Water resources	Increased evaporation rates
	Drier soil likely even if precipitation increases
	Decrease average run-off into streams
Fire	Hotter, drier conditions likely to increase bushfire risk

2.7 North East Water - Water Supply Demand Strategy

In 2005 North East Water established a project team to develop a Water Supply-Demand Strategy (WSDS) in response to the Victorian Government's Our Water Our Future action plan. The aim of the Strategy was to determine the expected long-term water demand for each of the water supply systems operated by North East Water and to identify the range of water supply-demand options based on economic, environmental and social criteria. Options considered included balancing water supply and demand, reducing water consumption, recycling, using alternative supplies and securing additional supplies through water trading and infrastructure programs.

2.7.1 Key findings

The predicted impacts of climate change on runoff in North-East Victorian basins (Table 14) were provided by DSE from work undertaken by CSIRO (Jones and Durack, 2005) based on the median climate change scenario.

Table 14 Predicted decline in runoff based on a median climate change scenario

Basin	2030	2055
Kiewa River	-9%	-19%
Ovens River	-12%	-24%
Upper Murray River	-9%	-19%

A step change climate change scenario was also undertaken and results suggest that the reduction in stream flows for the step-change scenario is worse for all systems than the median climate change scenario reported above. The modelling shows the security of the regulated Ovens system is unaffected under the step climate change scenario. However the unregulated Upper Ovens system is impacted as shown in the Table 15.

Table 15 Upper Ovens system reliability assuming step climate change

System	2004/5 existing reliability	2004/5 step climate change reliability	2054/55 step climate change reliability
Myrtleford	86%	80%	80%
Harrietville	68%	62%	59%
Bright	68%	62%	59%

In summary, to maintain 90% reliability, a Bulk Entitlement of greater than 130% of demand will be required.

2.8 Victorian DSE: Estimating the impacts of climate change on Victoria's runoff

In 2005 the Victorian Greenhouse Unit of the Victorian Department of Sustainability and Environment commissioned CSIRO to estimate the impacts of climate change on water yield (surface runoff and baseflow) within key Victorian water supply catchments. A simple hydrological model was used to estimate how mean annual flow may alter due to changes in rainfall and evapotranspiration under the low, median and high climate change scenarios for 2030 and 2070. The analysis did not consider variations in population demand, groundwater extractions or other externalities. This study was aimed at providing an indication of the direction and magnitude of possible changes in water supply. As such the approach simply applied the modified climate scenarios to the baseline calibrated model.

2.8.1 Key findings

Table 16 summarises the predicted change in runoff relative to historical conditions for 2030 wet, 2030 dry, 2070 wet and 2070 dry climate change scenarios.

Table 16 Change in runoff (% of annual average) for 2030 and 2070

	Runoff (GL)	Developed Yield (GL)	2030 wet (%)	2030 dry (%)	2070 wet (%)	2070 dry (%)
Kiewa River	679	9	0	-20	-5	>-50
Ovens River	1,692	26	0	-25	-5	>-50
Upper Murray River	2,803	838	0	-20	-5	>-50
Goulburn River	3,366	1,943	0	-35	-5	>-50
Broken River	326	32	0	-35	-5	>-50

3 PREVIOUS COMPANION STUDIES

The Southern Riverine Plains groundwater model developed by CSIRO/SKM as part of the Murray-Darling Basin Sustainable Yields project presents relevant information that may be utilised in future climate change studies in the region.

The Southern Riverine Plains (SRP) groundwater model was developed for the Murray-Darling Basin Authority Sustainable Yields Project and covers an area of approximately 1,800,000 ha. The model includes the major irrigation districts of Victoria including the Shepparton Irrigation District, the Campaspe region and the Loddon-Avoca regions (Figure 2). Also included is the New South Wales extent of the Murray region.

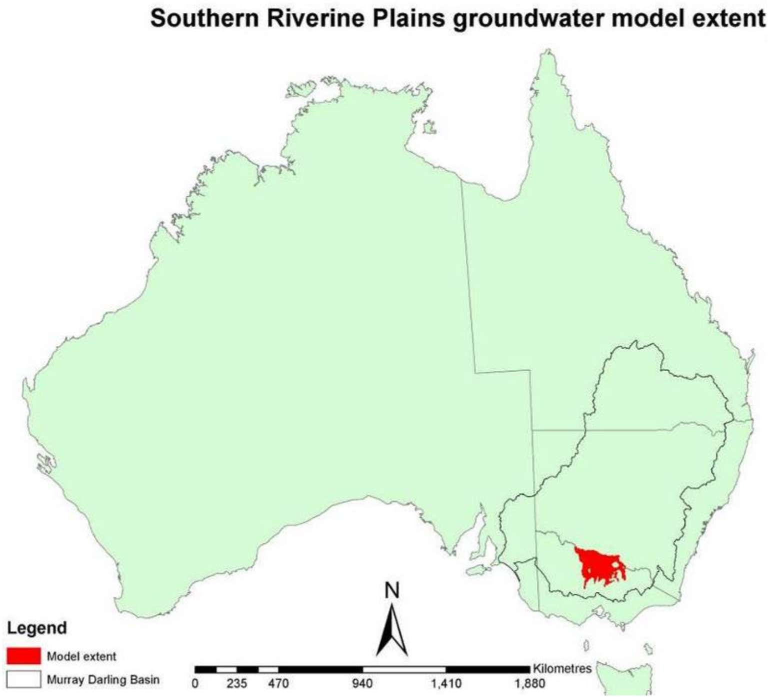


Figure 2 Location of the SRP study area in relation to the Murray-Darling Basin.

The Southern Riverine Plains is an area in which development of the groundwater resource has increased since the mid 1990s from 250 GL/yr to a peak of 400 GL in 2002/2003. In response to this increased development and in the context of prolonged drought and surface water supply shortages, this groundwater model was developed to provide a better understanding of the groundwater resource and its interaction with surface water resources under current and future climate conditions.

The SRP groundwater model covers an active area of 3,482,400 ha within the Murray-Darling Basin spanning either side of the Murray River between Yarrawonga and Swan Hill (Figure 3). Hydrogeologically the model includes the major parts of the Loddon River, Campaspe River, Goulburn River, Broken River, Wakool River, Edward River and Billabong Creek as reported in CSIRO (2008).

The groundwater management units within the model are the Murray (NSW), Loddon-Avoca (Vic), Campaspe (Vic), Goulburn-Broken (Vic) and Ovens (Vic). The Murray region includes the Lower Murray groundwater management unit (GWMA016) and the Katunga Water Supply Protection Area in addition to a small area around Gunbower Forest. The Loddon-Avoca region includes the Mid-Loddon GMA whereas the Campaspe region includes the

Campaspe Deep Lead WSPA and Ellesmere GMA. The Goulburn-Broken region includes the Mid-Goulburn GMA, Kialla GMA and Goorambat GMA. The Shepparton WSPA spans the Murray, Campaspe and Goulburn-Broken regions and refers specifically to the Shepparton Formation aquifer. In total the model covers nine individual groundwater management units and four regions. It also includes possible groundwater-dependent ecosystems including Gunbower Forest, Koondrook-Perricoota Forest and the Barmah Forest.

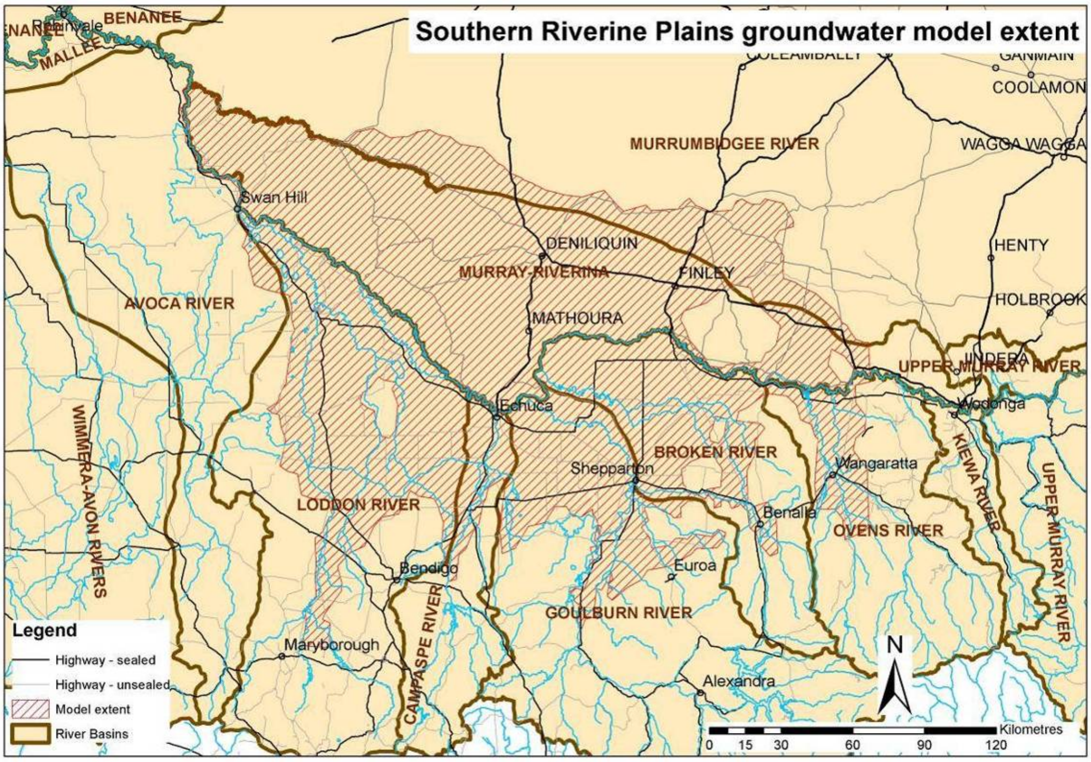


Figure 3 Active extent of the SRP groundwater model (shaded).

Upon calibration of the groundwater model to historical groundwater discharge and observation data for the period 1990 to 2006, the model was used to estimate the likely groundwater response under nine future scenarios. The nine scenarios are summarised in Table 17 and each scenario was run for 222 years so as to approach a 'dynamic equilibrium' state representing the long-term impact of stresses.

Irrigation was assumed to remain constant at rates and areas as per the 2004/2005 irrigation season. Recharge reduction factors were applied to all recharge areas as follows:

- Scenario A – 1.00
- Scenario B – 0.75
- Scenarios Cdry and Ddry – 0.66
- Scenarios Cmid and Dmid – 0.97
- Scenarios Cwet and Dwet – 1.14
- Without development scenarios – 1.00

Annual extraction rates were modified for Scenario D, with no groundwater extractions considered in the without development scenario.

The study reported groundwater water balance for specific groundwater management units (Campaspe Deep Lead WSPA, Ellesmere GMA, Goorambat GMA, Katunga WSPA, Kialla GMA and Lower Murray NSW GWMA016, Mid-Goulburn GMA, Mid-Loddon GMA and Shepparton WSPA) and regions (Campaspe, Goulburn-Broken, Loddon-Avoca and Murray). A typical water balance for the region is summarised in Table 18.

Table 17 Summary of scenarios used in the Sustainable Yields groundwater modelling.

A	Models current state of water resource development in the MDB. This includes current average annual surface water and groundwater diversions and current rates of irrigation.	Historical climate conditions from the period July 1895 to June 2006 (111 years)
B		Climatic conditions of the past ten years. For the Southern Riverine Plains region this represents drought conditions.
Cdry		A future climate scenario based on climate change predictions resulting in a drier climate compared to historical conditions.
Cmid		A future climate scenario based on best estimate or median levels of climate change. In the Southern Riverine Plains this results in a slightly drier climate.
Cwet		A future climate scenario based on climate change predictions resulting in a wetter climate compared to historical conditions.
Ddry	Models an inferred future state of water resource development.	As per Cdry
Dmid		As per Cmid
Dwet		As per Cwet
Without development	This scenario attempts to recreate conditions prior to the development of the groundwater resource.	As per scenario A

Table 18 Groundwater balance for the Sothern Riverine Plains region.

Groundwater balance	Without development	A	B	Cdry	Cmid	Cwet	Ddry	Dmid	Dwet
	GL/y								
Inflow									
Diffuse recharge	111.0	110.8	94.9	89.3	108.9	119.5	88.9	108.5	119.4
Head-dependent boundary	0.0	0.1	0.2	0.3	0.1	0.1	1.1	0.6	0.5
River recharge to groundwater	45.6	51.9	44.5	45.0	48.5	49.4	56.6	58.0	57.8
Groundwater inflows	36.8	32.6	32.0	31.7	32.5	32.9	30.7	31.2	31.5
Total inflows	193.4	195.4	171.6	166.3	190.0	201.9	177.3	198.3	209.2
Outflows									
Groundwater pumping	0.0	24.9	24.8	24.7	24.9	24.9	41.2	42.9	43.7
Head-dependent boundary	3.1	2.3	1.6	1.4	2.2	2.5	1.1	1.7	2.1
Groundwater outflows	56.4	70.3	70.1	70.3	70.3	70.4	76.7	75.5	75.0
Groundwater evapotranspiration	95.3	71.3	59.4	56.1	69.1	76.1	48.0	59.2	65.3
Discharge to drains	7.7	4.0	2.7	2.2	3.9	4.8	0.8	1.6	2.3
Discharge to rivers	30.8	22.5	13.1	11.7	19.6	22.9	9.8	17.4	20.6
Total outflows	193.3	195.3	171.7	166.4	190.0	201.6	177.6	198.3	209.0
Total river losses to groundwater	14.8	29.4	31.4	33.3	28.9	26.5	46.8	40.6	37.2

4 DPI CLIMATE CHANGE PREDICTIONS

The IPCC (2001) attributes most of the global warming observed over the last 50 years to greenhouse gases released by human activities. To estimate future climate change, the IPCC (SRES, 2000) prepared 40 greenhouse gas and sulphate aerosol emission scenarios for the 21st century that combine a variety of assumptions about demographic, economic and technologic driving forces likely to influence such emissions in the future. In the proceeding change analyses, three-climate scenarios (low, mid and high) inline with B2, A2 and A1F1 scenarios, respectively, of the IPCC (SRES, 2000) were generated using CSIRO's global atmosphere models (McGregor and Dix, 2001; Hennessy et al., 2006) integrated with annual global warming values (°C) (Figure 4).

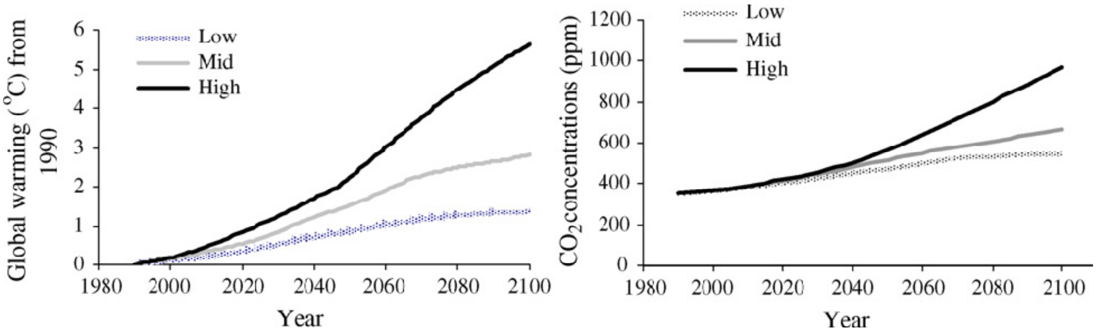


Figure 4 The annual global warming values (°C) and CO² concentrations (parts per million) for low, mid and high scenarios for years between 2000 and 2100 are relative to the IPCC (2001) standard 1990 baseline.

The CSIRO's global atmosphere model (CCAM) simulation is driven by CSIRO's Mark2 and Mark3 climate models, henceforth called CCAM (Mark2) and CCAM (Mark3). Both perform well over south-east Australia, although CCAM (Mark2) has a better simulation of average temperature. Hence, slightly more confidence can be placed in results from CCAM (Mark2). Climate projections from each model are considered independent since the Mark2 and Mark3 models have different parameterisations of physical processes. Regional climate change patterns from each model were expressed as a change per degree of global warming. This allows the results to be linearly scaled for any future year using the IPCC (2001) global warming estimates (Mitchell, 2003), which include the full range of IPCC SRES (2000) scenarios of greenhouse gas and aerosol emissions, and the full range of IPCC (2001) uncertainty in climate sensitivity to these emissions (Whetton, 2001). The regional climate change patterns underpinning the DPI climate change projections for the North-East CMA region are shown in Figure 5 to Figure 8 for rainfall, minimum temperature, maximum temperature and solar radiation respectively.

The historical sequence provides a reference or base line for current-non climate changed environment comparisons to some future environment. The comparisons, however, can be made in many ways and is somewhat dependent on the type of future data generated. DPI has adopted two methods. The first was the method of Suppiah et al. (2001) as applied by Anwar et al. (2007) to provide a continuous sequence that represents the non-stationery nature of climate change, i.e. increasing global warming trend each year applied to the historical sequence. The historical sequence is the basis of the future climate where autocorrelation is maintained. The advantage of this method is that it provides a realistic and smooth and complete sequence of weather data for analyses of an incremental nature over time. The disadvantage of the method is that stochastic variations consistent with a specific climate change scenario are not considered.

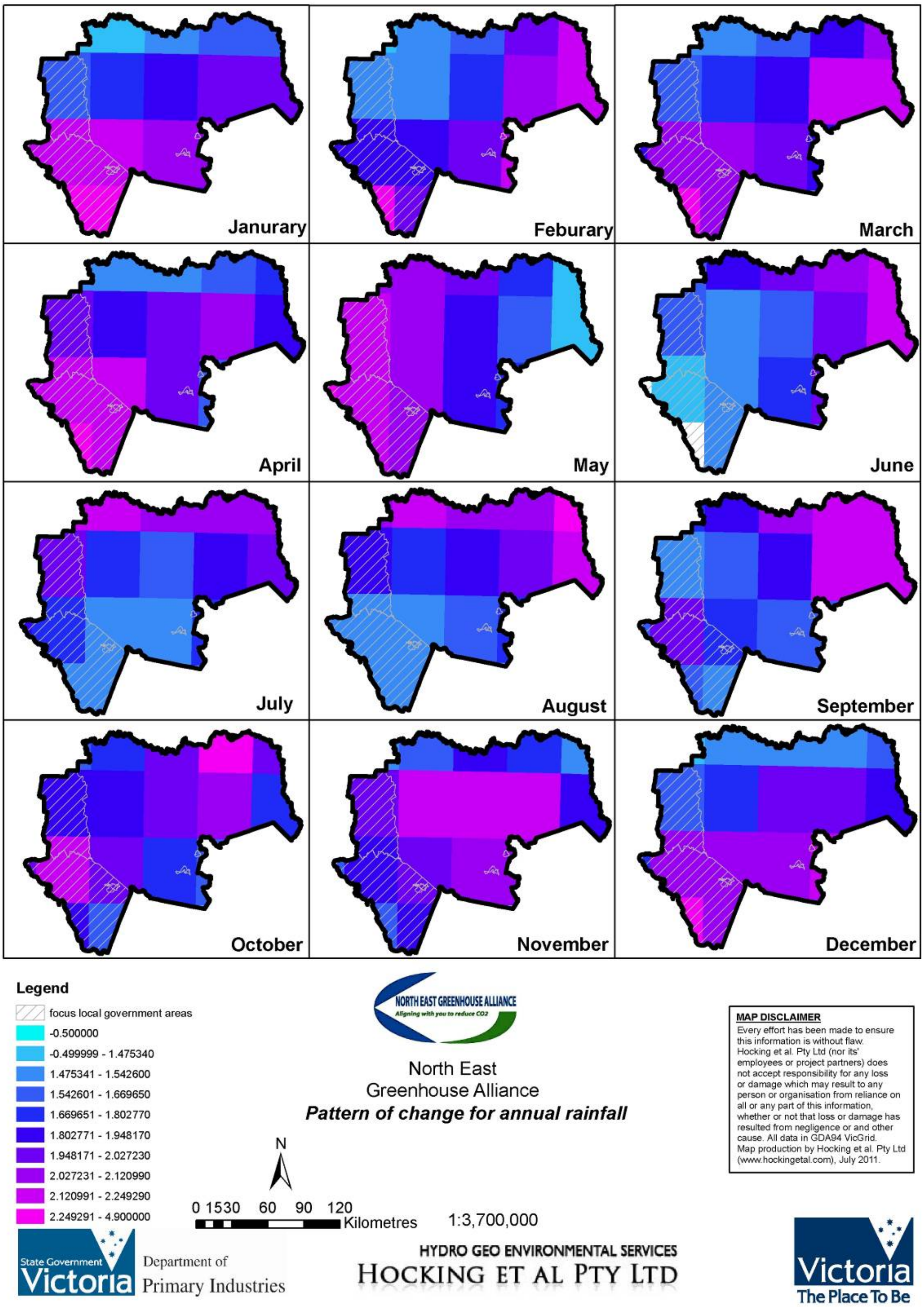


Figure 5 The regional rainfall climate change patterns for the North East and Goulburn Broken CMA regions.

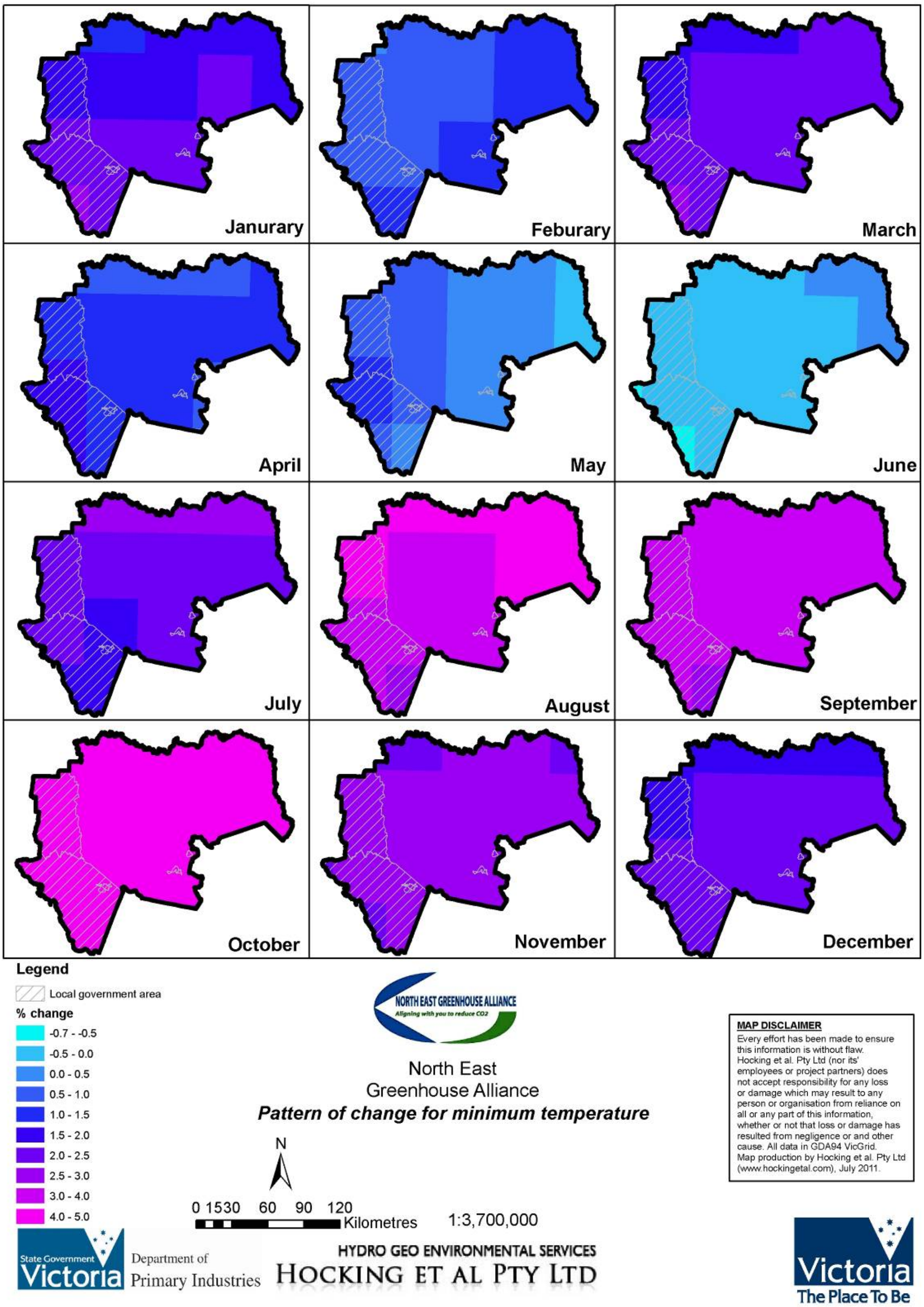


Figure 6 The regional minimum temperature climate change patterns for the Goulburn Broken and North East CMA regions.

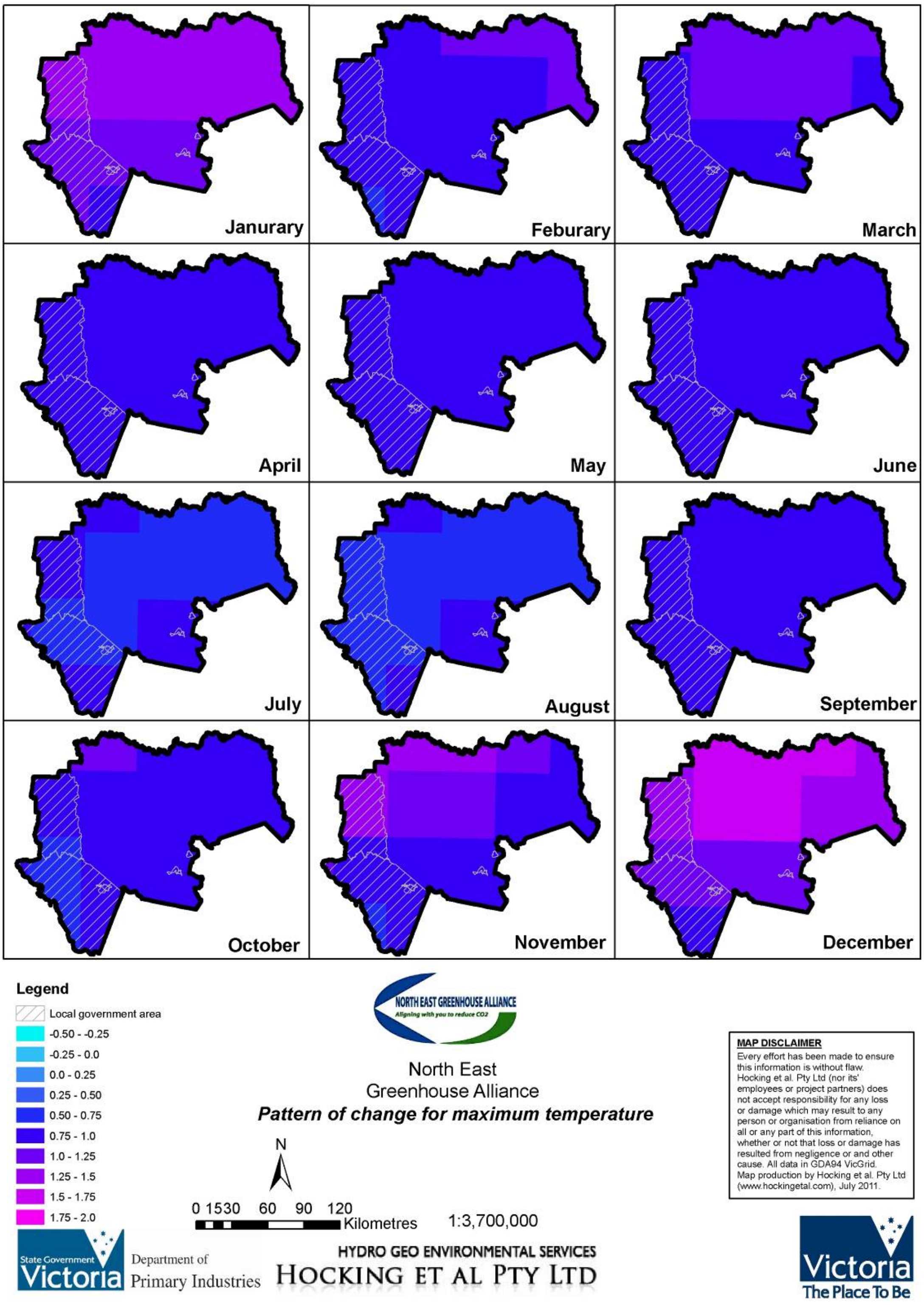


Figure 7 The regional maximum temperature climate change patterns for the Goulburn Broken and North East CMA region.

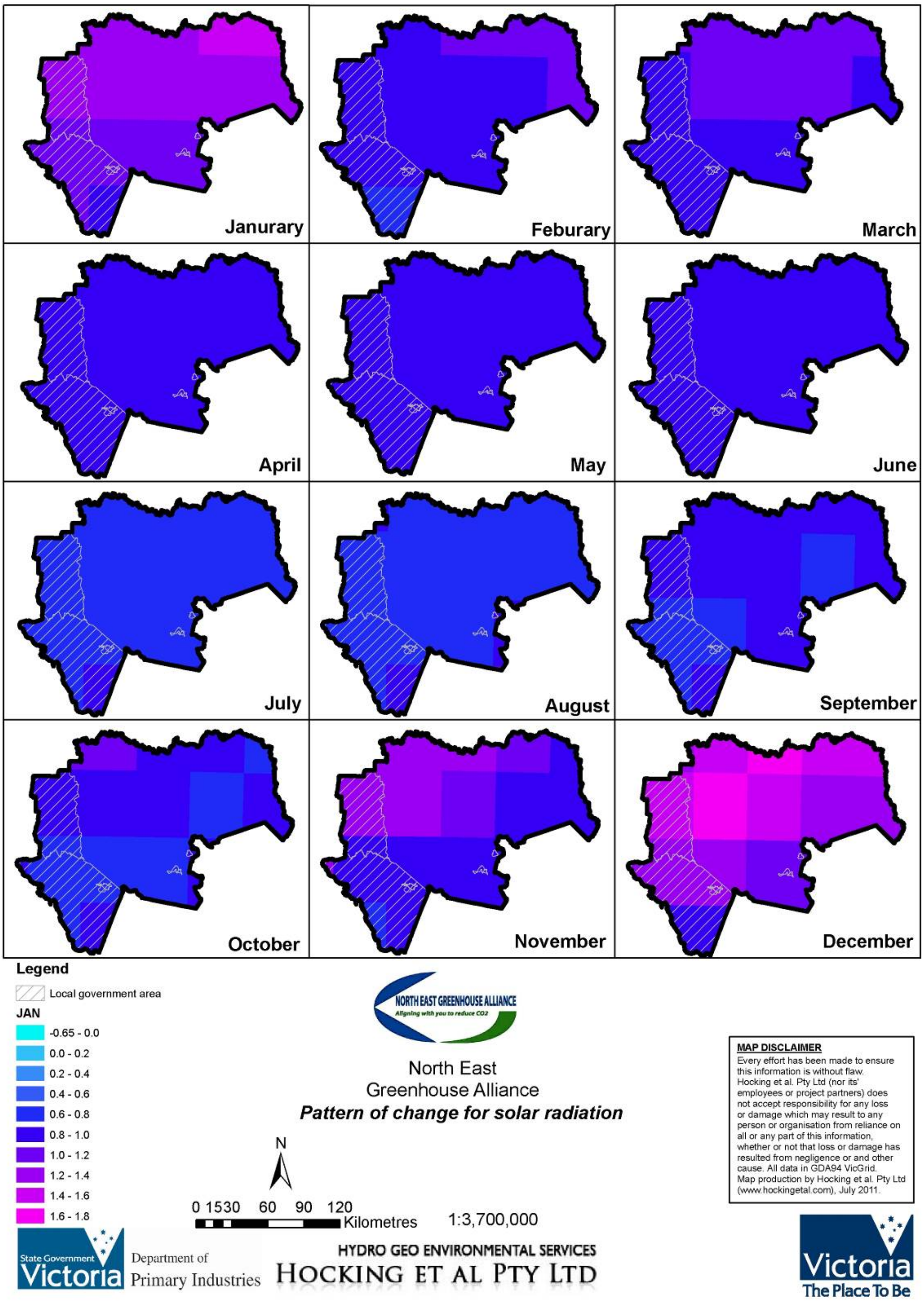


Figure 8 The regional solar radiation climate change patterns for the Goulburn Broken and North East CMA region.

4.1 Basic downscaling

DPI (O'Leary and Christy, 2009) developed two methods to generate future daily climate sequences for biophysical models. The choice of method depends on the nature and structure of the question being asked. The two methods are summarised as follows:

1. Method A is used when we are determining the impact of climate change over time series of numerous years. The aim of this method is to fix the daily climate sequence which at present uses past historic variance and incrementally change the CO_2, temperature, radiation and rain pattern of change impacts over time. For example if we were testing the impact of climate change on a groundwater systems which takes 20 years to respond to any change imposed then Method A should be used.
2. Method B is used when we are determining the impact of climate change at a single point in time in the future (say 2030 for example). The aim of this method is to fix the CO_2, temperature, radiation and rain pattern of change impacts to that future point in time and change many years of daily climate data to represent the year 2030. This method allows the prediction of the distribution of biophysical response over a range of years.

The process of deriving future daily climate sequences requires the determination of patterns of climate change per degree of global warming on a monthly basis for four climate variables (rainfall, maximum and minimum temperature, and solar radiation) across Victoria (Hennessy et al., 2006). In this application the pattern was applied to 71 years (1935–2005) of daily data for each of the 71 climate stations within the study region (obtained from SILO patch-point, http://plum.nre.vic.gov.au/silo/) to create a 71-year future scenario from 2000 to 2070 by Method B.

Table 19 shows the Method A procedure applied to generate daily future climate scenarios for maximum temperature. A similar procedure was performed for minimum temperature, rainfall and solar radiation applying the relevant monthly pattern of change and global warming value to each observed daily matrix. This procedure identifies changes in the monthly maximum and minimum temperatures, rainfall and solar radiation and these changes (positive or negative) which are subsequently applied in the methodology to create daily future climate (2000–2070) scenarios. As such this method assumes that the identical sequence of the de-trended historical data (1935–2005) is applied to future climate but the monthly means are amended to reflect the future climate scenarios. Minimum and maximum temperature patterns have units of $^{o}C/^{o}C$ and base climatology (average temperature for 1961–1990) units are ^{o}C. Rainfall patterns have units in $\%/^{o}C$ and base climatology (average rainfall for 1961–1990) units are mm. Solar radiation patterns have units of $\%/^{o}C$ and base climatology (average radiation for 1961–1990) units are MJ/m2.

To deal with stochastic options that give a realistic analysis representative of any particular future year, e.g. 2030 or 2070, a sequence of years is needed to represent the future year (Method B, Table 20). We achieved this by applying the de-trended historical data referenced to the base year to the particular year of interest by applying the global warming factor for that year to the whole data sequence so that it is shifted vertically (in this maximum temperature example). This means that for each future year we have a sequence of weather data having the same number of years as the historical data. This method allows the climate change effect to be analysed without confounding between individual years.

Both methods assume that the autocorrelation between years that exists in the historical data are applied to all sequences applied to any future years. They, however, does not address extreme events that are predicted to increase in intensity and frequency due to progressive climate change.

The results reported in this study based on the DPI derived climate scenarios were developed using Method B.

Table 19 Method A to create daily future climate (2000–2070) scenarios using the outputs from CSIRO's global atmosphere models (CCAM-Mark2 and CCAM-Mark3).

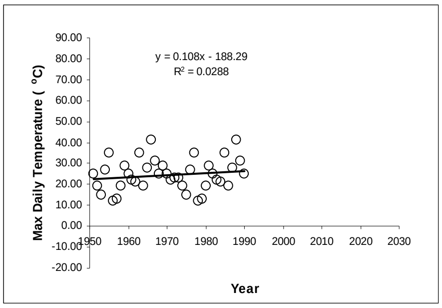
<table>
<tr><td colspan="2">This is the method of Anwar et al. (2007) and provides a sequence of weather data consistent with a specific climate change scenario.</td></tr>
<tr><td>Step</td><td>Mathematical and graphical expression</td></tr>
<tr><td>Create an anomaly series with no time-trend for all climate stations.</td><td>xJan19yy = xJan19yy(observed) _ TJan *(19yy-1935) _ MJan</td></tr>
<tr><td>First, calculate trends for each calendar month for each station, then subtract the trend-increment from the daily data. This de-trended time-series will have a monthly mean of M.</td><td>Example: Determine trend in historical time series.


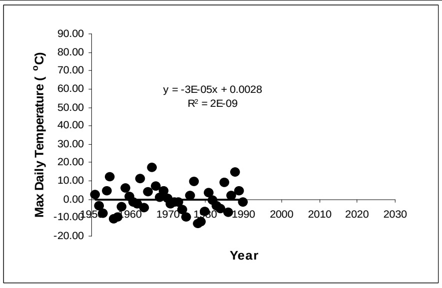
Figure 1. Example historical trend over time in maximum daily temperature for January.</td></tr>
<tr><td>Second, subtract M to create a monthly anomaly time-series with a mean of zero, e.g., assume the January mean is MJan and the max temp trend is TJan °C /year at a each station, and the first year of record is 1935, then the de-trended anomaly value for the xth day of January in year 19yy is xJan19yy.</td><td>

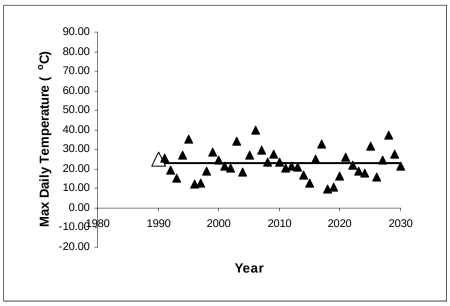
Figure 2. Example de-trended maximum daily temperature for January.</td></tr>
<tr><td>Estimate a baseline value (Baseline1990) for the year 1990, for each calendar month, based on the observed linear monthly trend from 1935 to 1990. This is needed to anchor the projections from the IPCC reference year of 1990.</td><td>Baseline1990Jan = MJan + TJan * (1990–1935)/2


Figure 3. Example de-trended maximum daily temperature for January raised to the reference year 1990 and projected into the future.</td></tr>
<tr><td>Xjan19yy is the de-trended xth day of January maximum temperature for year 19yy for each station (as above) (°C). Example B is 9 January 1965.</td><td>B = [37 °C]</td></tr>
</table>

<table>
<tr><td>Incorporate CSIRO's global atmosphere models (CCAM-Mark2 and CCAM-Mark3) 50_50 km gridcell pattern (Pat) for Victoria.</td><td>Pat = [1.1 1.1 1.1 1.1 1.0 1.01.0 0.9 0.8] PatB = [1.0]</td></tr>
<tr><td>Pat is the January pattern of change for maximum temperature (°C per degree of global warming) from the climate model across Victoria. PatB is the selected Cell representing a climate station.</td><td></td></tr>
<tr><td>The global warming database (°C) contains low, mid and high values for each year (2000–2070) and was used to scale de-trended observed daily data from years 1935 to 2005 for each climate station.</td><td>2000 low00 mid00 high00
2001 low01 mid01 high01
.
. 2030 low30 mid30 high30
.
2070 low70 mid70 high70</td></tr>
<tr><td>Generate a daily maximum temperature scenario using the low global warming scenario. x is the day of the month. Values for the first (second, third, etc.) year in the de-trended observed time-series are scaled by the first (second, third, etc.) year in the global warming dataset. The process is the same for mid or high global warming scenario—this procedure was repeated for mid and high scenarios.</td><td>xJan2000 = xJan1935 + baseline1990Jan + (Pat * low00)
xFeb2000 = xFeb1935 + baseline1990Feb + (Pat * low00)
…

xJan2001 = xJan1936 + baseline1990Jan + (Pat * low01)
xFeb2001 = xFeb1936 + baseline1990Feb + (Pat * low01)
…

xJan2070 = xJan2005 + baseline1990Jan + (Pat * low70)
xFeb2070 = xFeb2005 + baseline1990Jan + (Pat * low70)

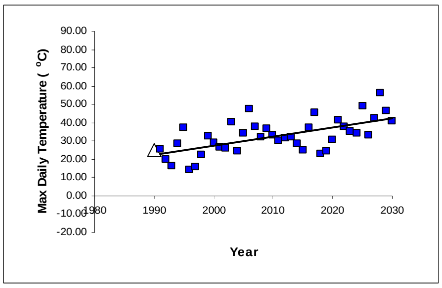


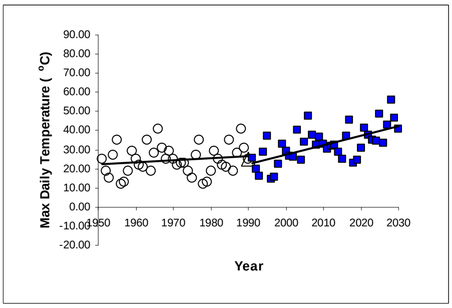
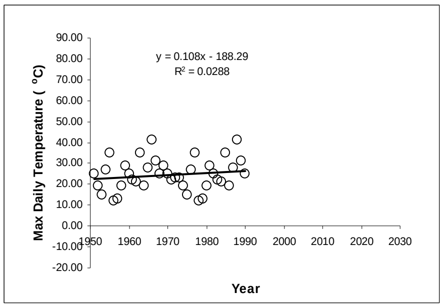
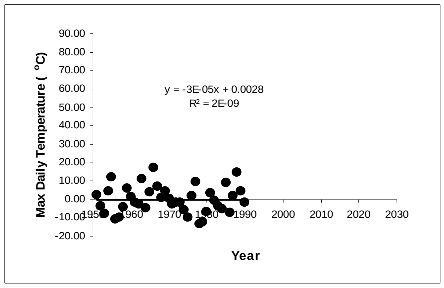
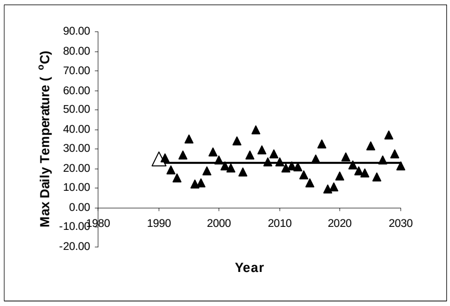
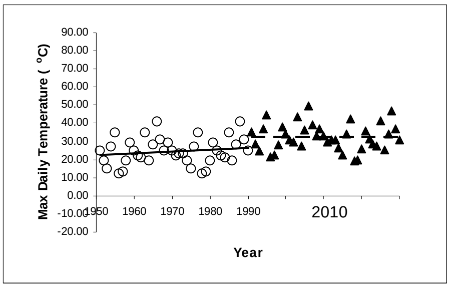
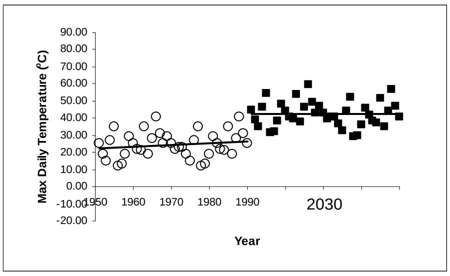
Figure 4. Example global warming factor applied for each year to the de-trended maximum daily temperature for January that had been raised to the reference year 1990 and projected into the future.


Figure 5. Comparison of the historical (circles) and high global warming scenario (squares) daily maximum temperature for January.</td></tr>
<tr><td>To the right is a hypothetical example for 9 January 2030 maximum temperature (°C) derived from de-trended data for 9 January 1965 and the high global warming scenario</td><td>Assuming B and PatB values from above, and assuming high30 = 1.5 in the global warming database, then Jan2030high = [37.9 °C]</td></tr>
</table>

Table 20 Method B to create daily future climate scenarios for a single future year (e.g. 2030) using the outputs from CSIRO's global atmosphere models (CCAM-Mark2 and CCAM-Mark3).

This is a variation of Method A and provides a sequence of weather data weather data having the same number of years as the historical data for any future year of interest. Note that both methods are identical until the point of adding the global warming database value.	
Step	**Graphical expression**
Create an anomaly series with no time-trend for each climate station.	xJan19yy = xJan19yy(observed) _ TJan *(19yy-1935) _ MJan
First, calculate trends for each calendar month for each climate station, then subtract the trend-increment from the daily data. This de-trended time-series will have a monthly mean of M.	Example: Determine trend in historical time series.  Figure 1. Example historical trend over time in maximum daily temperature for January.
Second, subtract M to create a monthly anomaly time-series with a mean of zero, e.g., assume the January mean is MJan and the max temp trend is TJan ^{o}C /year at each climate station, and the first year of record is 1935, then the de-trended anomaly value for the xth day of January in year 19yy is xJan19yy.	 Figure 2. Example de-trended maximum daily temperature for January.
Estimate a baseline value (Baseline1990) for the year 1990, for each calendar month, based on the observed linear monthly trend from 1935 to 1990. This is needed to anchor the projections from the IPCC reference year of 1990.	Baseline1990Jan = MJan + TJan * (1990–1935)/2  Figure 3. Example de-trended maximum daily temperature for January raised to the reference year 1990 and projected into the future.
Xjan19yy is the de-trended xth day of January maximum temperature for year 19yy for each climate station (as above) (^{o}C). Example B is 9 January 1965.	B = [37 ^{o}C]
Incorporate CSIRO's global atmosphere models (CCAM-Mark2 and CCAM-Mark3) 50_50 km gridcell pattern (Pat) for Victoria (see example Figure 2).	Pat = [1.1 1.1 1.1 1.1 1.0 1.01.0 0.9 0.8] PatB = [1.0]
Pat is the January pattern of change for maximum temperature (^{o}C per degree of global warming) from the climate model across Victoria. PatB is the selected Cell representing a climate station.	
The global warming database (^{o}C) contains low, mid and high values for the year (2030) and was used to	2030 low30 mid30 high30

scale de-trended observed daily data from years 1935 to 2005 for each climate station.	
Raise or decrease the de-trended data by the respective pattern of change for the specific location and global warming factors for future year of interest.	 Figure 6. The de-trended data from the base year has been amended by the global warming and pattern of change factors representative of the year 2010.
Each year of interest (e.g. 2030) requires a data sequence comparable to the historical sequence.	 Figure 7. The de-trended data from the base year has been amended by the global warming and pattern of change factors representative of the year 2030.

4.2 Change in rainfall and temperature from the historical climate pattern

The projected climate change scenarios are based on 1935-1990 historical climate data using the Method B described above. This enables a comparison of the daily climate change scenario data with the baseline historical data. This section presents the departure from the historical annual rainfall and mean daily temperature climate pattern under the assumed 2030 and 2070 climate regimes for each of the LGAs. The aggregated climate data was generated based on a derived Voronoi diagram that maps the spatial extent of each climate station within each LGA. Data from all climate stations identified within each shire were aerially weighted to derive an aggregated climate data set for each climate regime and subsequently used in the comparisons presented below.

Figures 4.2.1 to 4.2.10 show the spatially averaged change in mean annual rainfall (mm/yr) and average daily temperature (^{o}C) relative to the 1990 condition for the Falls Creek Alpine Resort, Mount Buller/Mount Stirling Alpine Resort, Mount Hotham Alpine Resort, Benalla Rural City and Mansfield Shire Councils. The climate station annual variability is reported in Figure 9 to Figure 20. Table 21 summarises the mean annual rainfall (mm/yr) and average daily temperature (^{o}C) for each LGA under various climate change projections. The corresponding relative changes to 1935-1990 conditions in mean annual rainfall (mm/yr) and average daily temperature (^{o}C) for each local government area under various climate change projections are summarised in Table 22. Results suggest that the Alpine shire consistently is most impacted with regards to temperature for each climate projection whereas the order of rainfall impact varies between regions and future scenarios.

Table 21 Mean annual rainfall (mm/yr) and average daily temperature (ºC) for local government focus areas under various climate projections.

	Historic	2030			2070		
	1935-1990	Low	Medium	High	Low	Medium	High
	Mean annual rainfall (mm/yr)						
Benalla	756	727	716	702	705	666	614
Mansfield	1136	1099	1085	1067	1071	1020	953
Mt Stirling	1451	1405	1387	1364	1368	1304	1217
Mt Buller	1452	1405	1387	1365	1369	1304	1218
Mt Hotham	1820	1739	1717	1696	1693	1612	1555
Falls Creek	2076	1986	1960	1942	1933	1841	1782
	Mean daily temperature (^{o}C)						
Benalla	14.4	15.1	15.4	15.9	15.8	17.0	18.7
Mansfield	12.0	12.3	12.9	13.3	13.2	14.4	15.9
Mt Stirling	9.3	9.9	10.2	10.6	10.5	11.7	13.3
Mt Buller	9.3	9.9	10.2	10.6	10.5	11.7	13.3
Mt Hotham	6.2	6.7	7.1	7.4	7.4	8.6	10.1
Falls Creek	8.6	9.2	9.5	9.9	9.9	11.0	12.6

Table 22 Percentage change in mean annual rainfall (mm/yr) and average daily temperature (ºC) for local government focus areas under various climate projections.

	2030			2070		
	Low	Medium	High	Low	Medium	High
	Percentage change in mean annual rainfall (%) from 1935-1990 conditions					
Benalla	-3.9	-5.3	-7.7	-7.2	-13.5	-23.1
Mansfield	-3.3	-4.7	-6.4	-6.1	-11.4	-19.2
Mt Stirling	-3.3	-4.6	-6.4	-6.1	11.3	19.2
Mt Buller	-3.3	-4.7	-6.4	-6.1	-11.3	-19.2
Mt Hotham	-4.7	-6.0	-7.3	-7.5	-12.9	-17.0
Falls Creek	-4.5	-5.9	-6.9	-7.4	-12.8	-16.5
	Percentage change in mean daily temperature (%) from 1935-1990 conditions					
Benalla	4.6	6.5	9.4	8.9	15.3	23.0
Mansfield	2.4	7.0	9.8	9.1	16.7	24.5
Mt Stirling	6.1	8.8	12.3	11.4	20.5	30.1
Mt Buller	6.1	8.8	12.3	11.4	20.5	30.1
Mt Hotham	7.5	12.7	16.2	16.2	27.9	38.6
Falls Creek	6.5	9.8	13.1	13.1	21.8	31.7

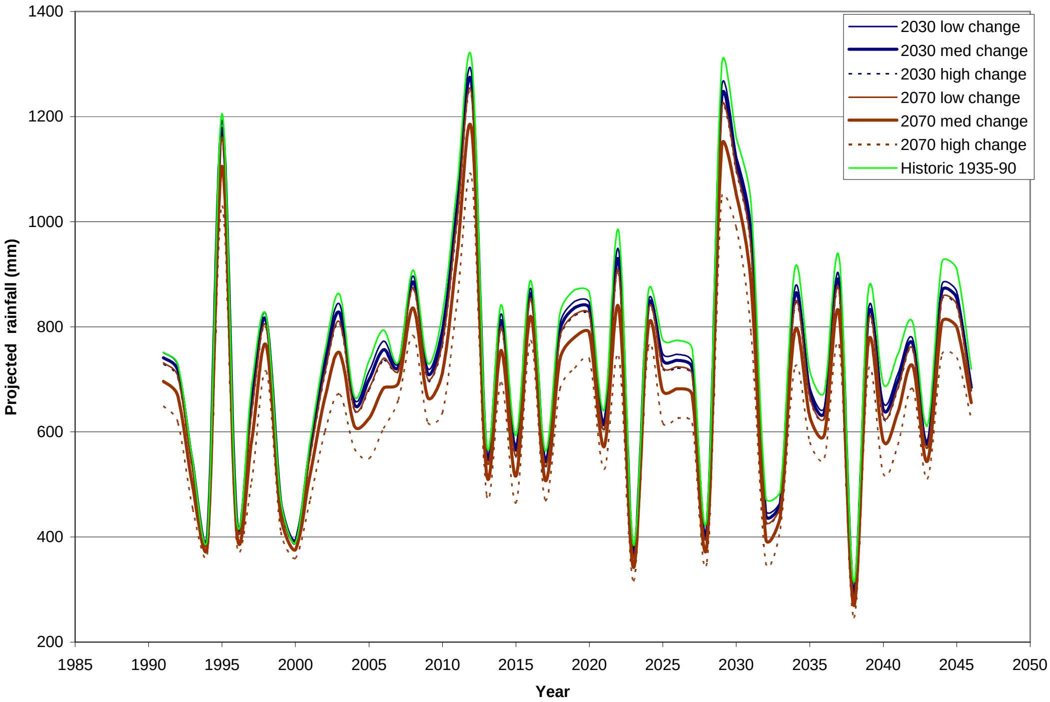


Figure 9 Variation in rainfall for Benalla Rural City under various climate change scenarios.

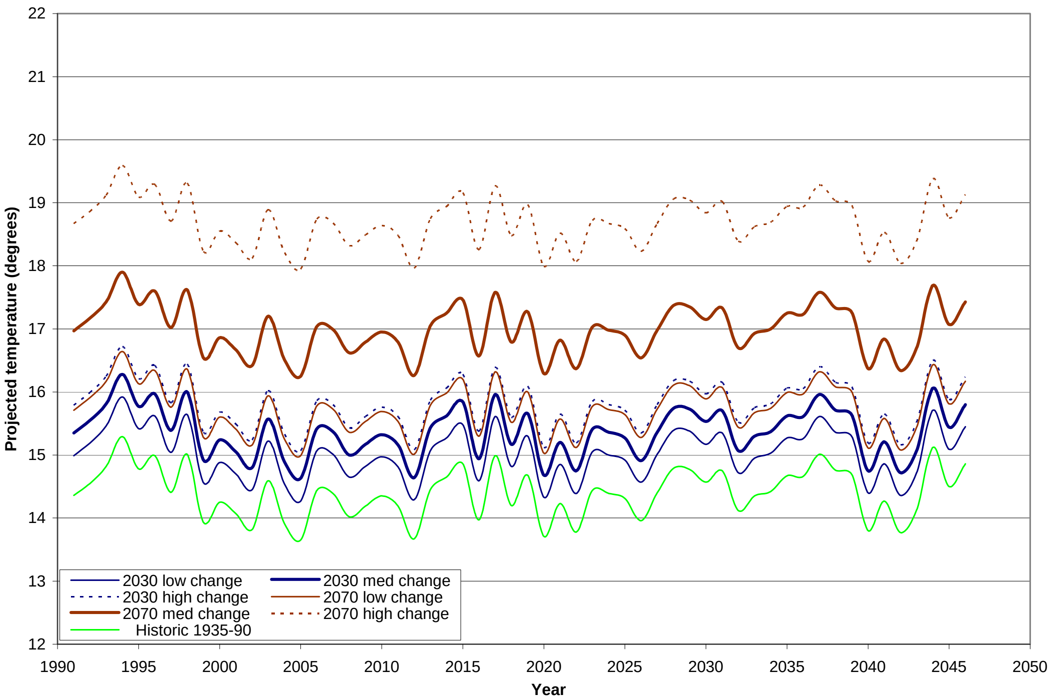


Figure 10 Projected mean daily temperature (°C) for Benalla Rural City under various climate change scenarios.

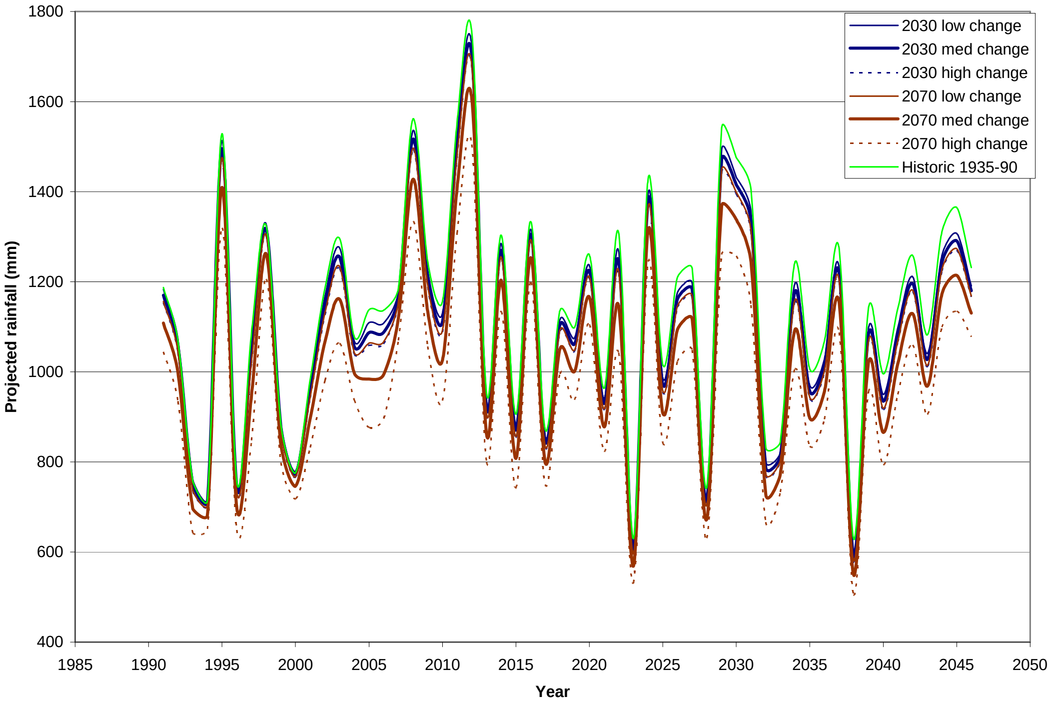


Figure 11 Variation in rainfall for Mansfield Shire Council under various climate change scenarios.

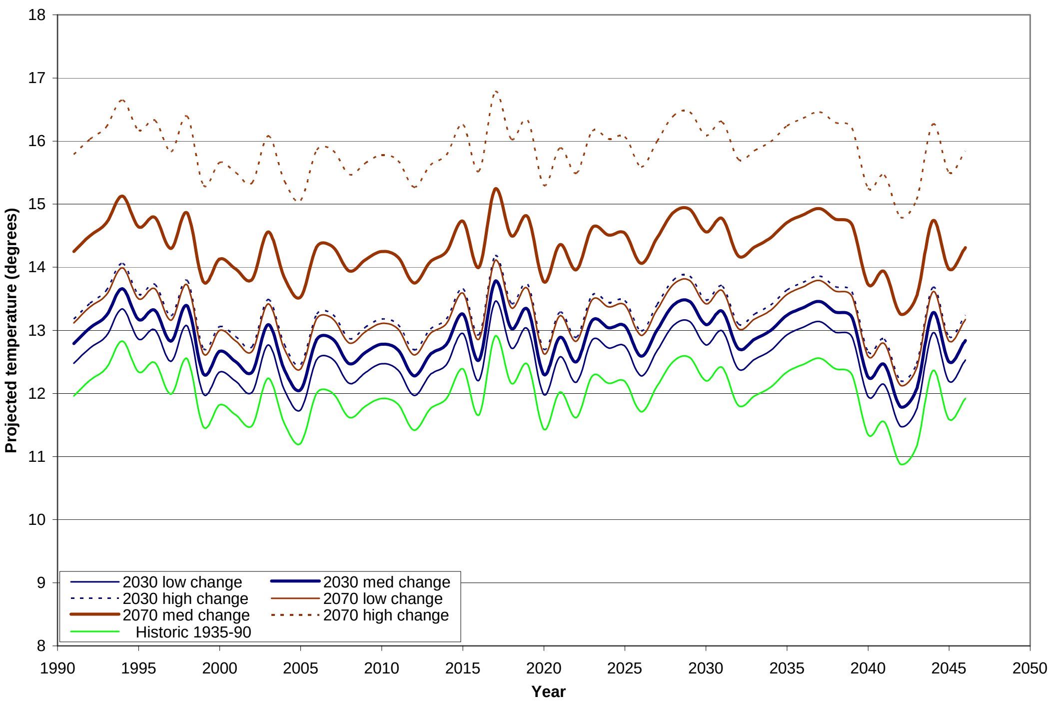


Figure 12 Projected mean daily temperature (°C) for Mansfield Shire Council under various climate change scenarios.

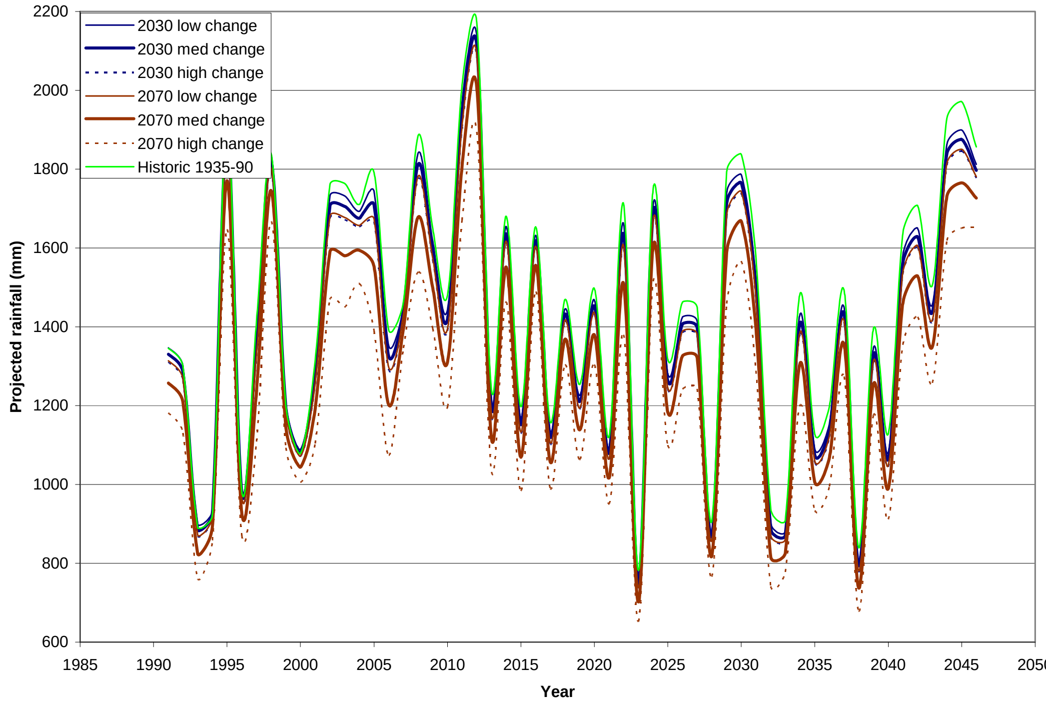


Figure 13 Variation in rainfall for Mt Stirling Alpine Resort under various climate change scenarios.

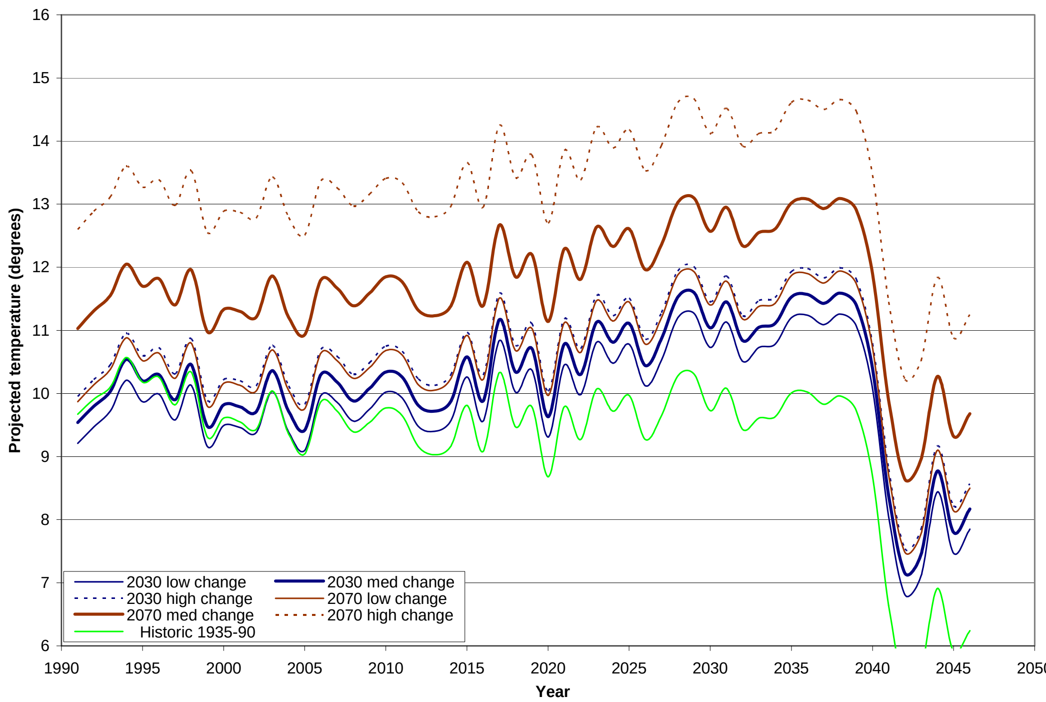


Figure 14 Projected mean daily temperature (°C) for Mt Stirling Alpine Resort under various climate change scenarios.

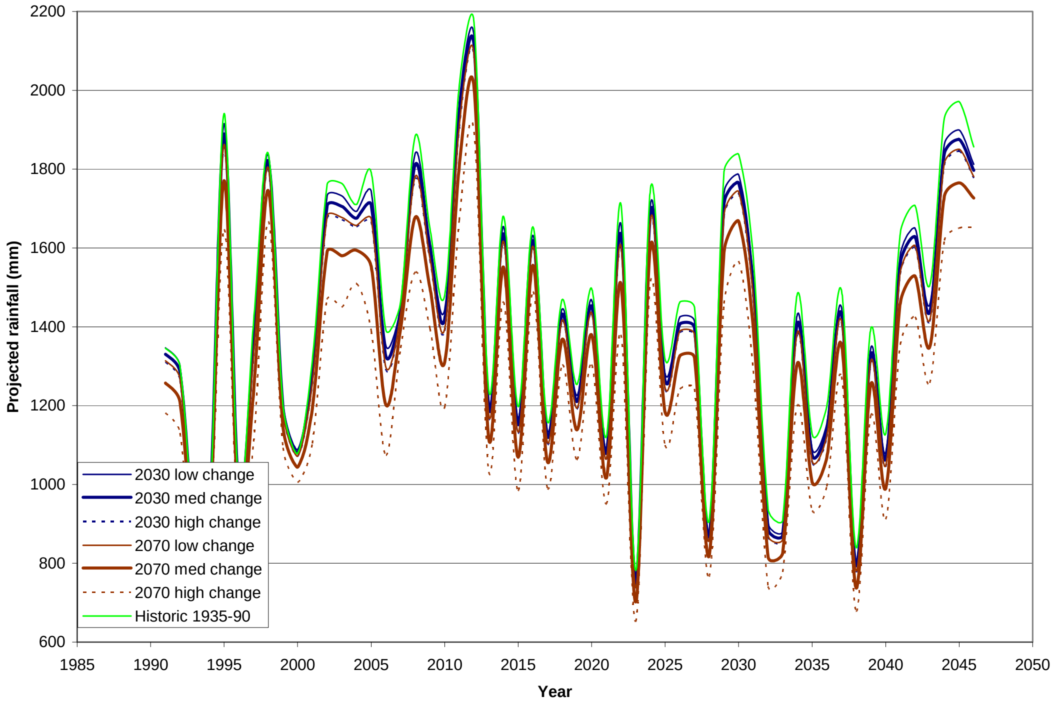


Figure 15 Variation in rainfall for Mt Buller Alpine Resort under various climate change scenarios.

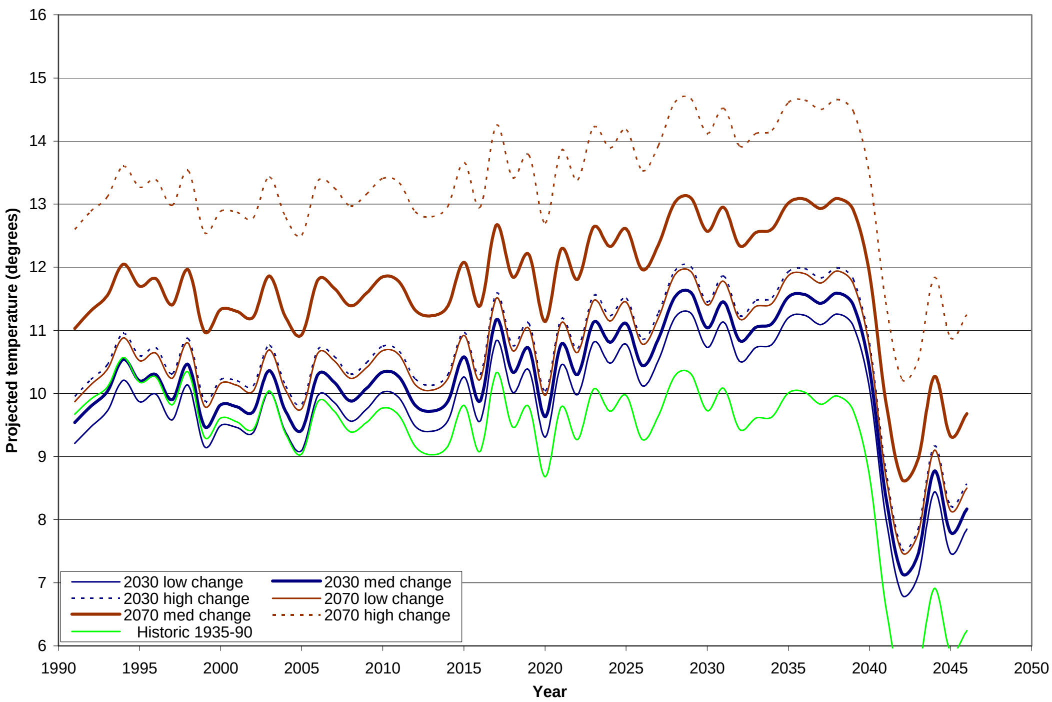


Figure 16 Projected mean daily temperature (°C) for Mt Buller Alpine Resort under various climate change scenarios.

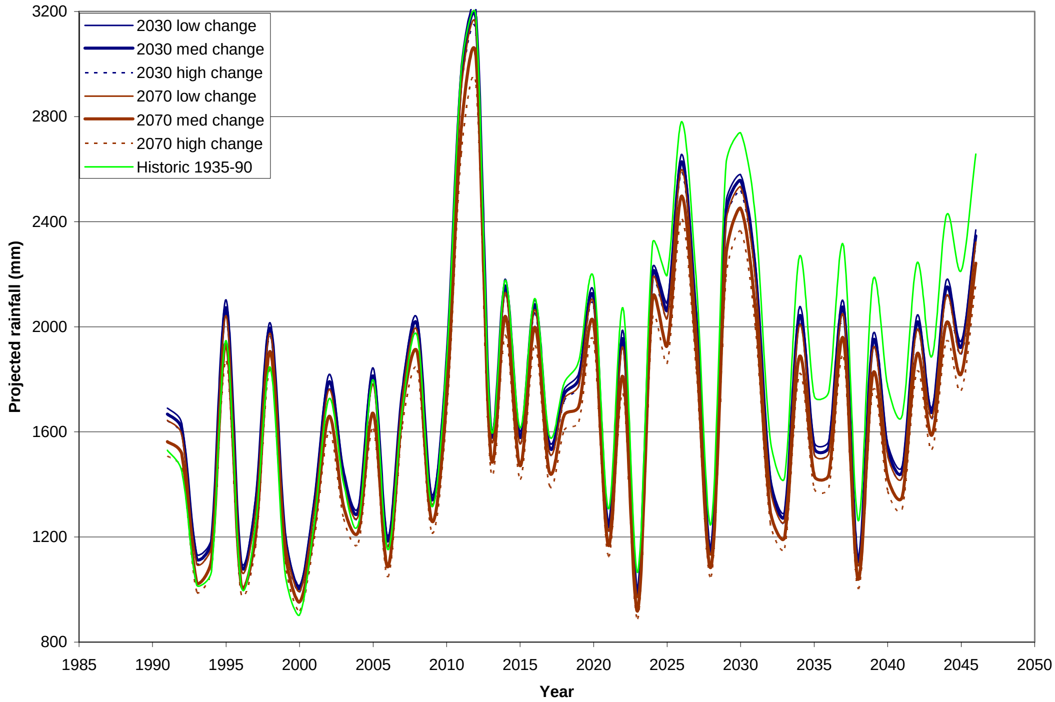


Figure 17 Variation in rainfall for Mt Hotham Alpine Resort under various climate change scenarios.

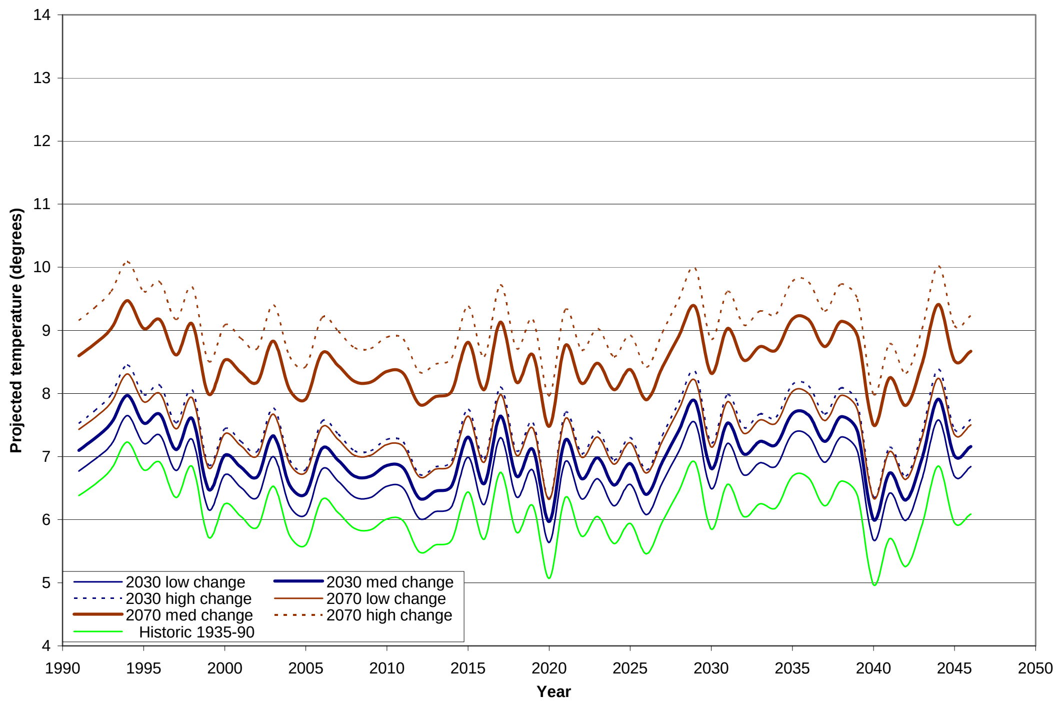


Figure 18 Projected mean daily temperature (°C) for Mt Hotham Alpine Resort under various climate change scenarios.

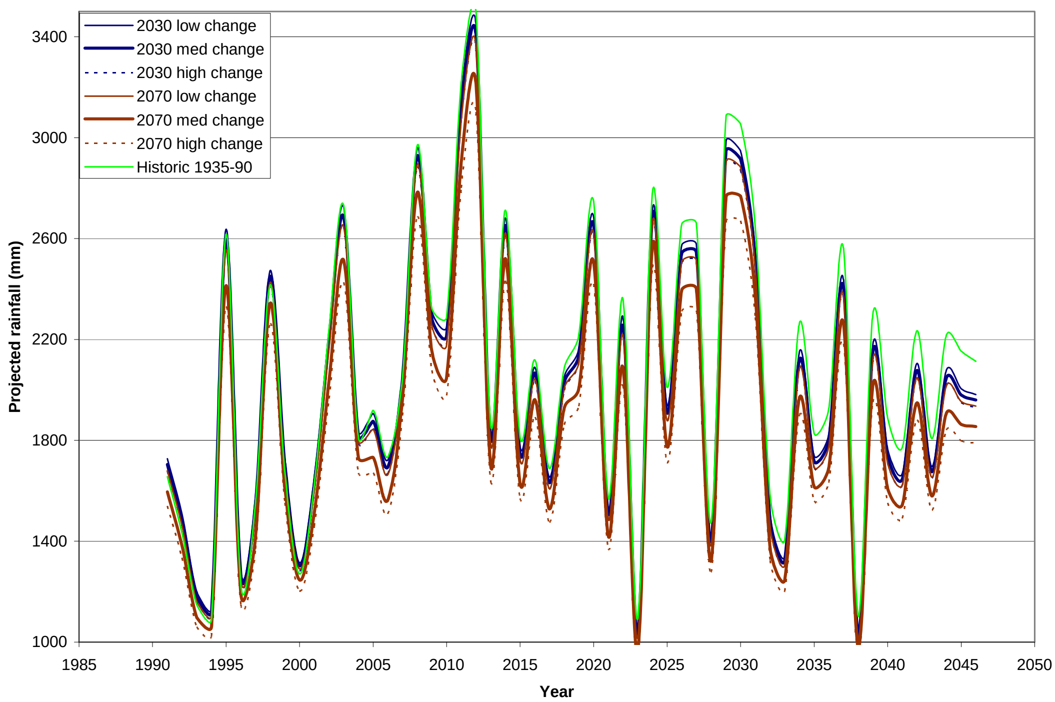


Figure 19 Variation in rainfall for Falls Creek Alpine Resort under various climate change scenarios.

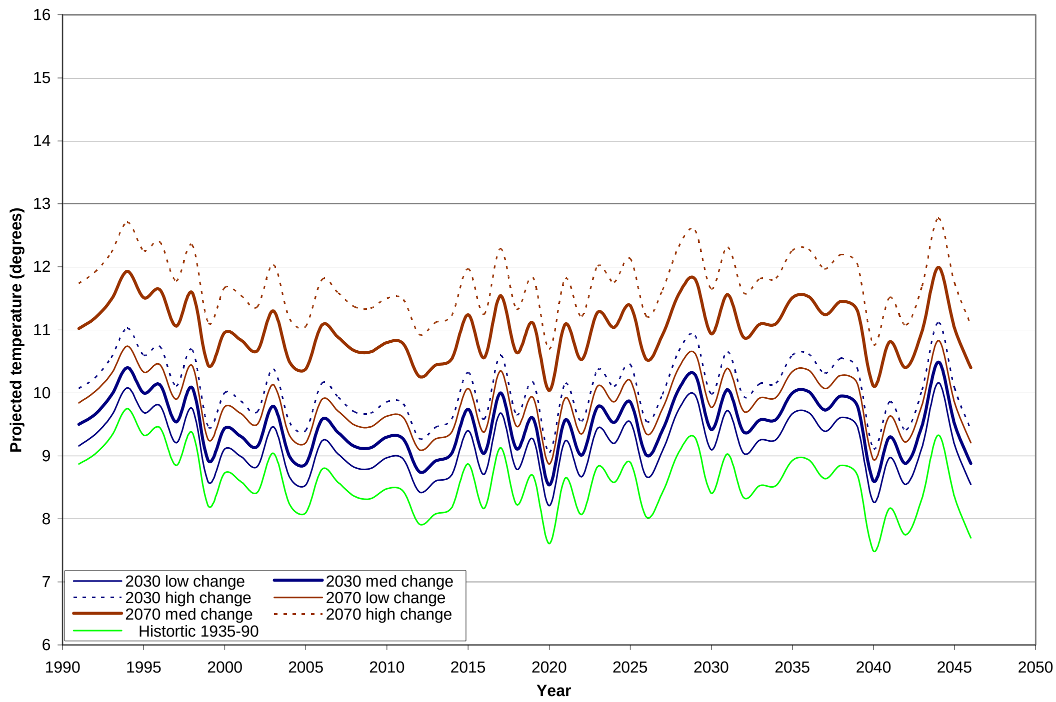


Figure 20 Projected mean daily temperature (°C) for Falls Creek Alpine Resort under various climate change scenarios.

4.3 Results – water balance summaries

Summarised below are the percentage variation in water balances relative to historical 1957 to 2005 conditions under current and future climate scenarios for the North-East CMA region, local government areas and specific catchments. The future climate scenarios accounted for elevated CO_2 impacts on vegetation response under reduced rainfall and increased temperature and solar radiation conditions.

4.3.1 Mean annual water balance for North East and Goulburn Broken CMA regions

The variations in mean annual water balance components from historic (1957-2005) for the entire North-East and Goulburn Broken CMA regions are summarised in Table 23 and Table 24.

Table 23 North-East CMA region future climate percentage change in water balance from historical (1957-2005).

	1995-	2030			2070		
	2005	Low	Medium	High	Low	Medium	High
Rainfall	-4	-3	-4	-5	-5	-10	-16
Runoff	-4	-23	-28	-33	-31	-44	-55
Evapotranspiration	2	-0.4	-0.2	-0.1	0.1	-0.1	-2
Recharge	-11	-7	-10	-14	-14	-25	-38
Streamflow	-14	-5	-9	-14	-13	-25	-39
Total flow	-17±3	-7±2	-12±2	-18±3	-17±3	-31±6	-49±9

Table 24 Focus LGAs within Goulburn Broken CMA future climate percentage change in water balance from historical (1957-2005).

	1995-	2030			2070		
	2005	Low	Medium	High	Low	Medium	High
Rainfall	-7	-2	-4	-6	-5	-11	-20
Runoff	-6	-21	-27	-34	-30	-45	-61
Evapotranspiration	2	-0.2	-0.1	-0.0	0.0	-0.2	-3
Recharge	-15	-4	-7	-9	-7	-31	-42
Streamflow	-16	-4	-8	-13	-12	-27	-41
Total flow	-19±3	-8±2	-11±2	-16±3	-15±3	-33±6	-50±9

4.3.2 Mean annual water balance for LGA regions

The change in mean annual rainfall (mm/y) for each LGA region for the 2030 and 2070 climate change scenarios are graphically shown in Figure 21 and Figure 22 respectively. Also shown is the 1995-2005 condition. The corresponding recharge variations are shown in Figure 23 and Figure 24 whereas the runoff impacts are shown in Figure 25 and Figure 26.

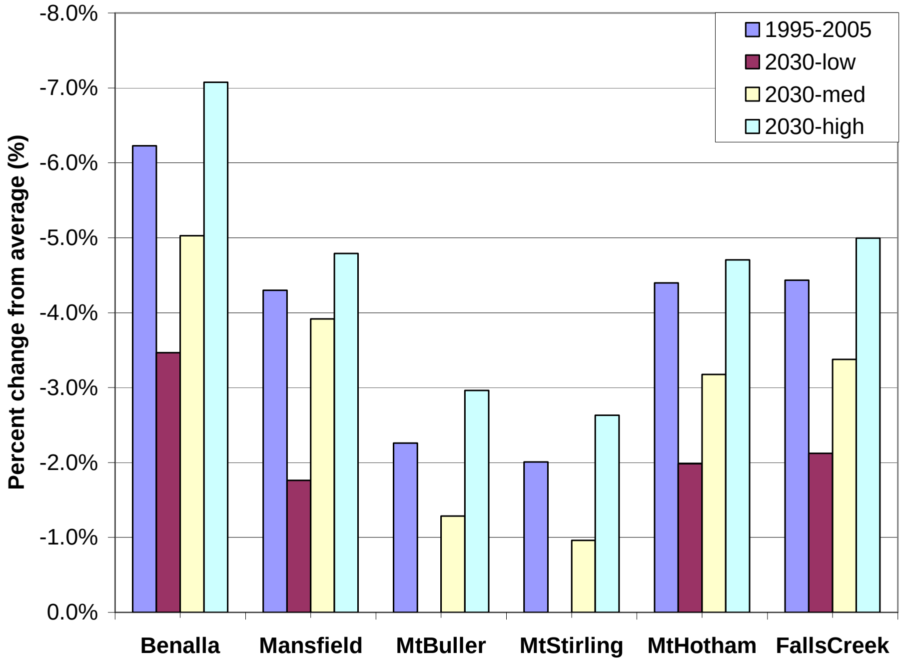


Figure 21 Change in rainfall (%) under 2030 climate change scenarios for each local government area. Also shown is the 1995-2005 response.

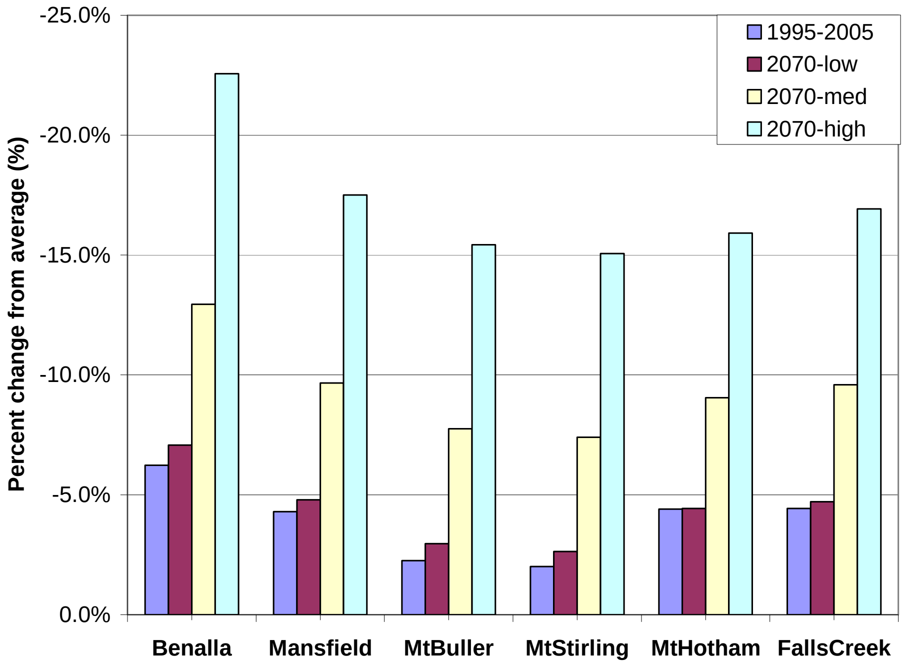


Figure 22 Change in rainfall (%) under 2070 climate change scenarios for each local government area. Also shown is the 1995-2005 response.

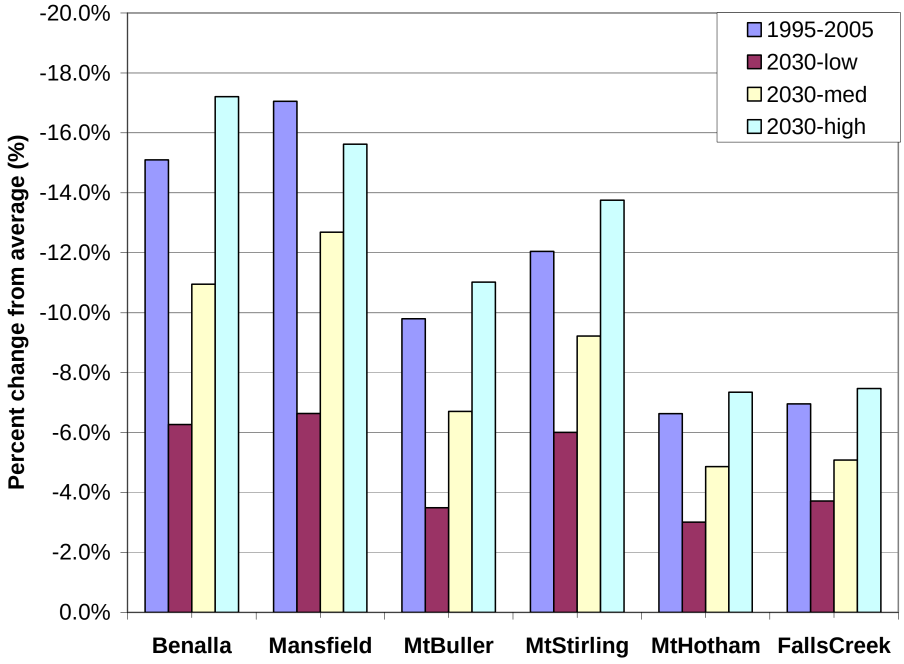


Figure 23 Change in recharge (%) under 2030 climate change scenarios for each local government area. Also shown is the 1995-2005 response.

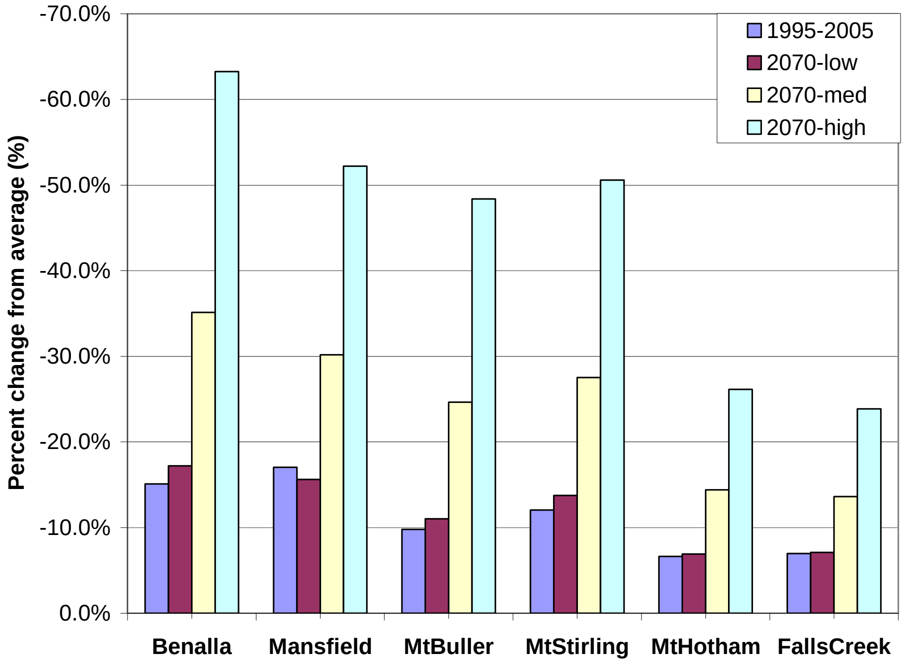


Figure 24 Change in recharge (%) under 2070 climate change scenarios for each local government area. Also shown is the 1995-2005 response.

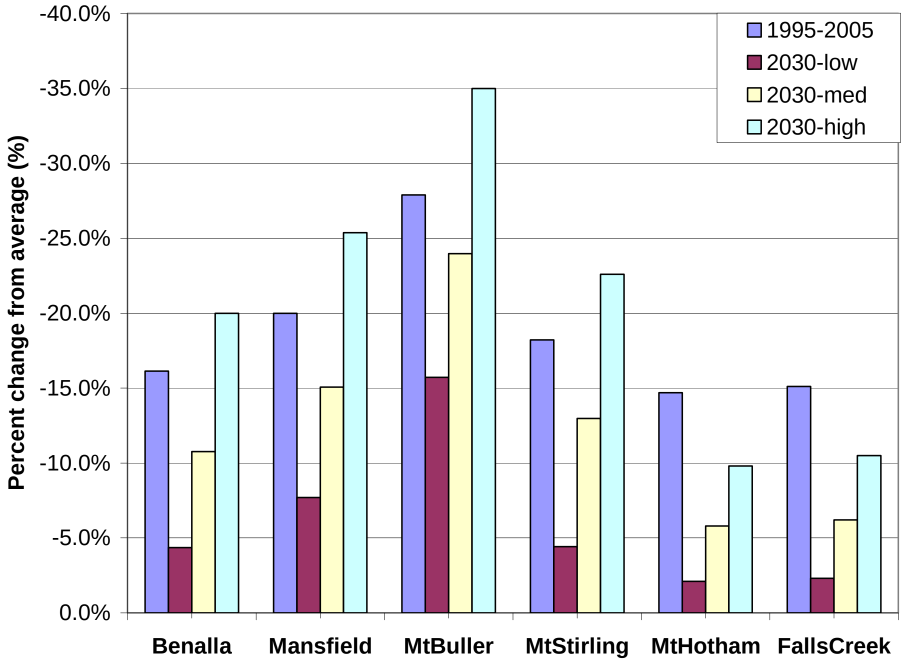


Figure 25 Change in runoff (%) under 2030 climate change scenarios for each local government area. Also shown is the 1995-2005 response.

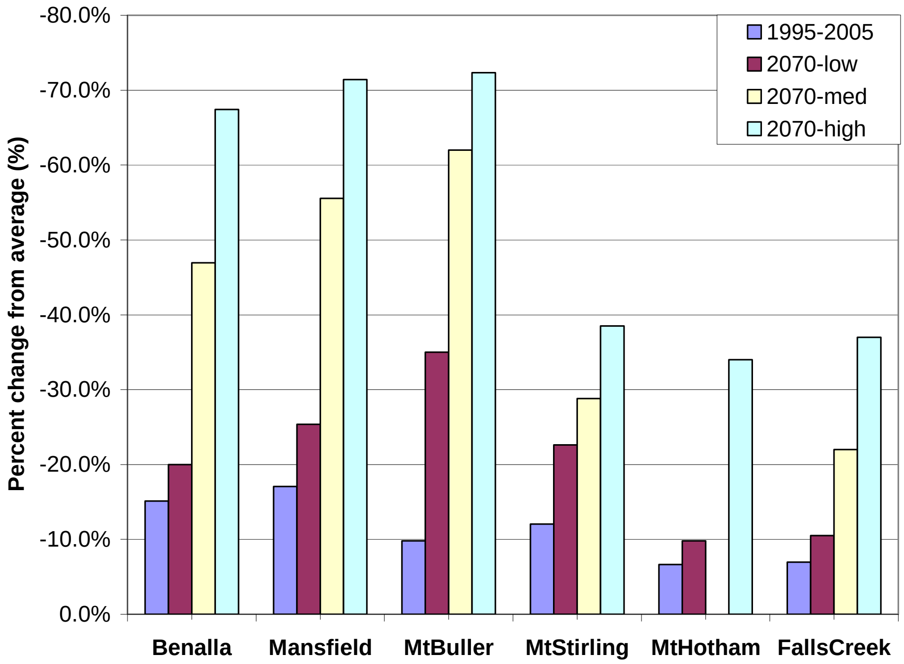


Figure 26 Change in runoff (%) under 2070 climate change scenarios for each local government area. Also shown is the 1995-2005 response.

4.3.4 North East CMA groundwater response under climate change scenarios

The likely impact of climate change on groundwater dynamics was evaluated using the multi-layered fully distributed groundwater model MODFLOW (McDonald and Harbaugh, 1988) and was developed. The groundwater conceptualisation adopted a six-layer framework accounting for the dominant geological groups, specifically the Coonambidgal Formation, upper and lower Shepparton Formations, Calivil Formation, the deeply weathered geology and the Palaeozoic basement. The grid resolution was 200m x 200m and as such this model has a finer spatial scale and more detail than the CSIRO Southern Riverine Plains groundwater model. Groundwater extraction data were provided by Goulburn-Murray Water. Whereas the groundwater model used in this study has been calibrated for the period 1990-2000, results reported hereafter are based on steady state solutions thereby representing the dynamic-equilibrium state in accord with the CSIRO Sustainable Yields project. The groundwater mass balance under current conditions is shown in Table 27.

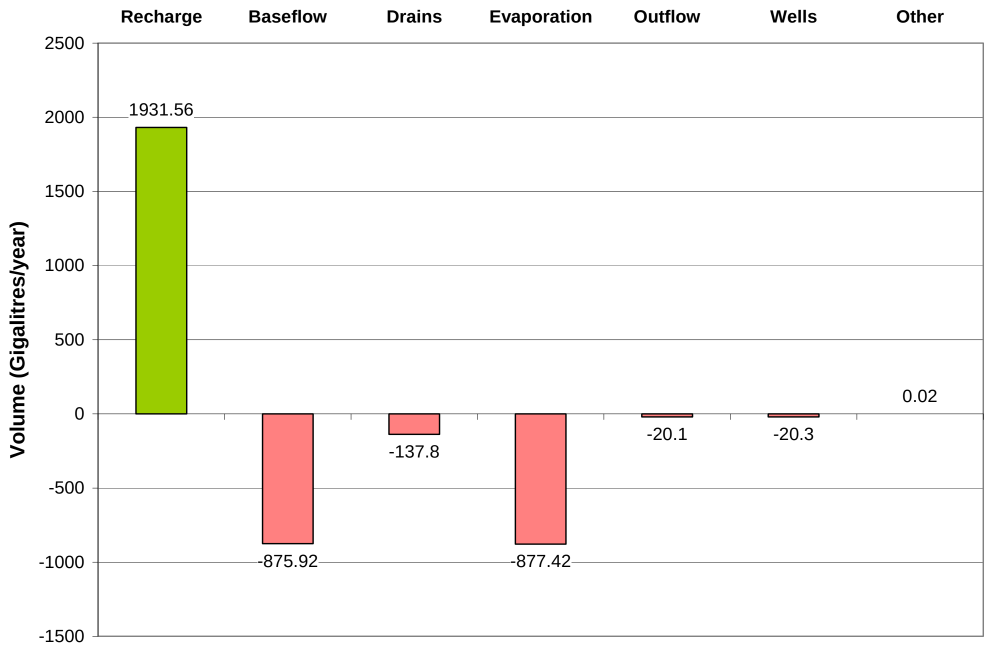


Figure 27 Groundwater mass balance under current conditions.

Spatial variation in groundwater recharge under differing climate change scenarios is presented in Figure 28 to Figure 30.

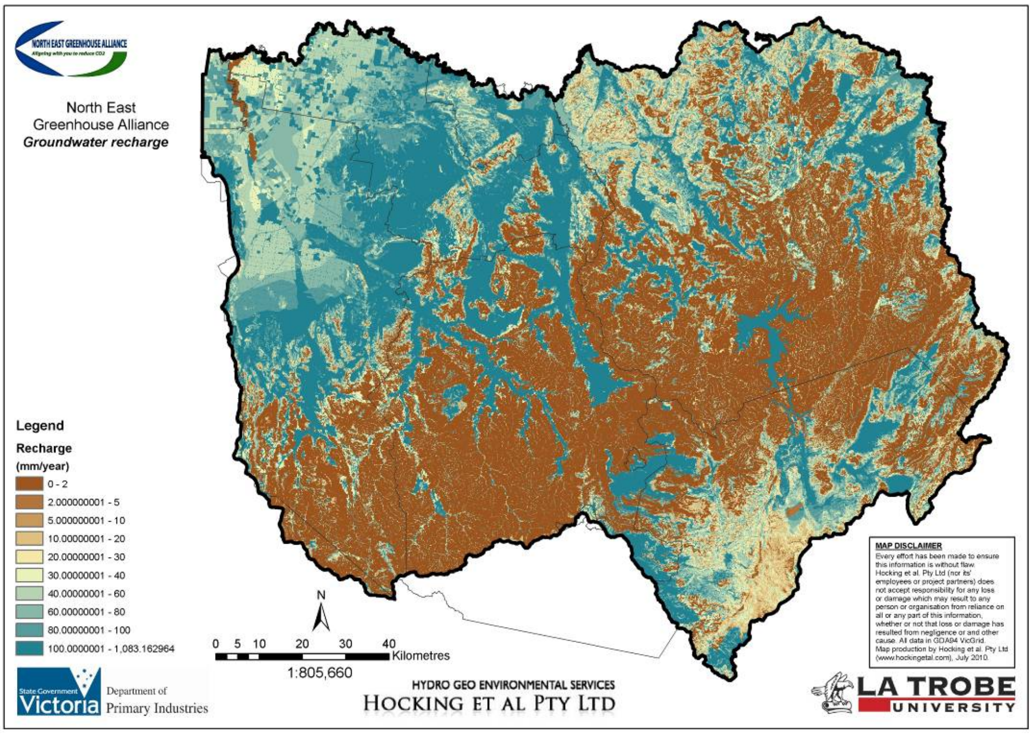


Figure 28 Mean annual groundwater recharge (mm/yr) under current conditions (from Beverly & Hocking 2010).

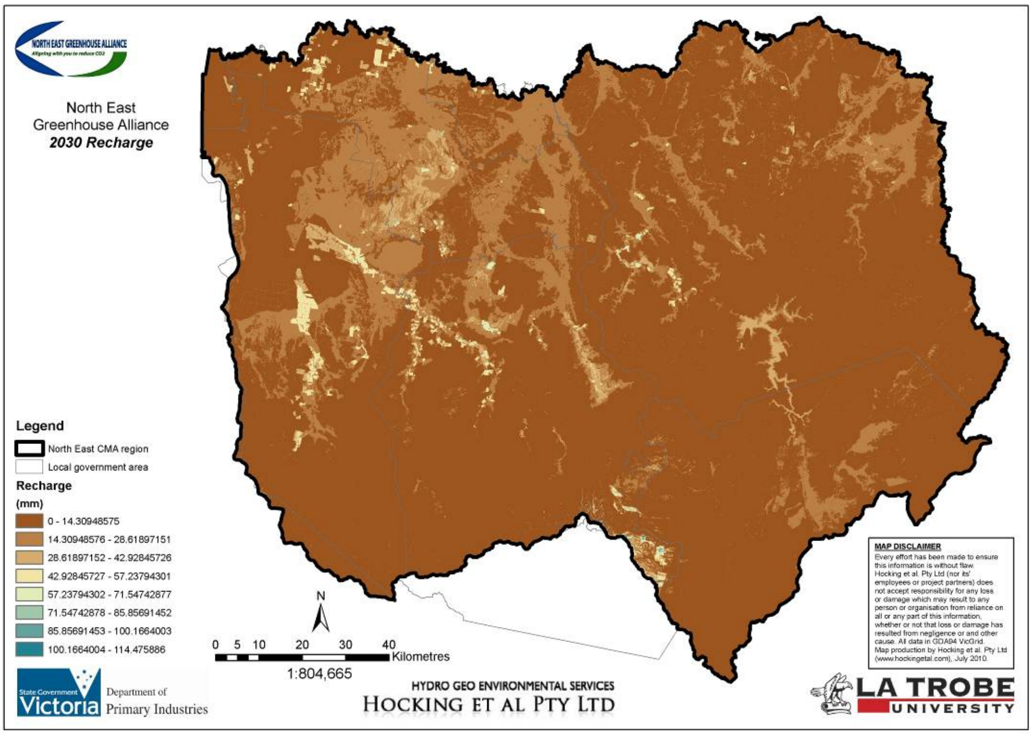


Figure 29 Mean annual groundwater recharge (mm/yr) under 2030 medium climate change conditions (from Beverly & Hocking 2010).

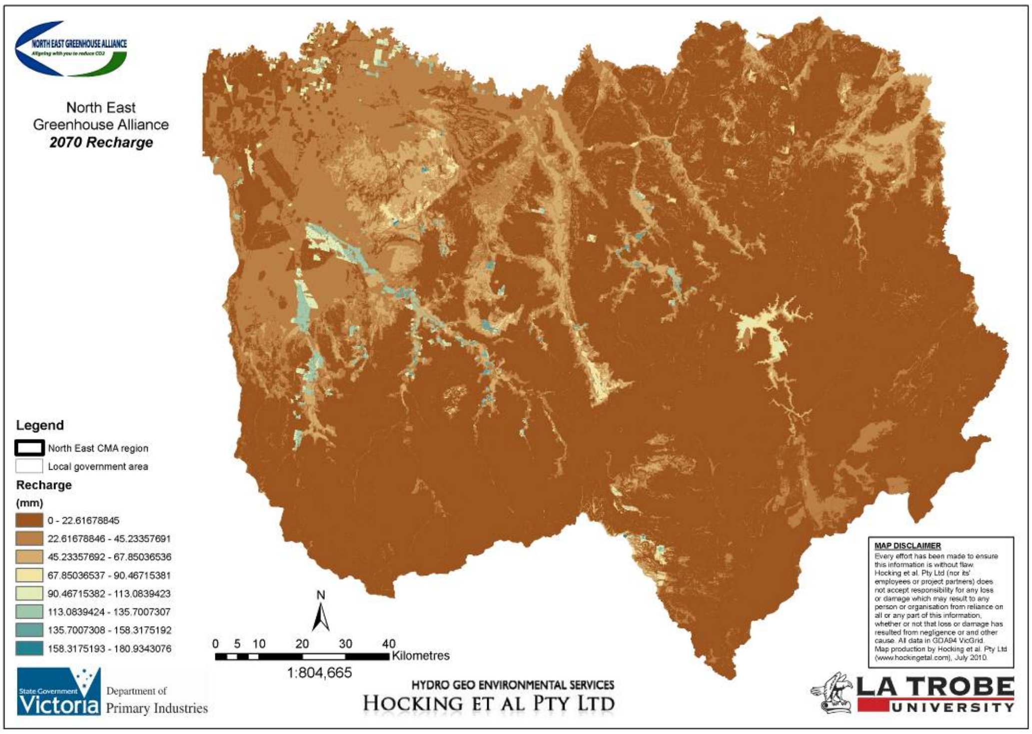


Figure 30 Mean annual groundwater recharge (mm/yr) under 2070 medium climate change conditions (from Beverly & Hocking 2010).

The change in total groundwater volume under different climate scenarios are summarised in Table 25, Table 26 and Table 27 for the Local Government Areas. The corresponding changes in groundwater elevation relative to current condition for each scenario are shown in Appendix B.

Table 25 Change in groundwater storage (GL) from current condition under various climate scenarios for the total North-East CMA region.

Scenario	Change in groundwater storage from current
1995-2005	5222
2030 low	2507
2030 med	5042
2030 high	8823
2070 low	4806
2070 med	8975
2070 high	14737

4.3.5 Goulburn Broken CMA groundwater response under climate change scenarios

Simular to the above North East CMA groundwater simulations, the Goulburn Broken CMA was also considered. The likely impact of climate change on groundwater dynamics was evaluated using the multi-layered fully distributed groundwater model MODFLOW (McDonald and Harbaugh, 1988) and was developed. The groundwater conceptualisation adopted a six-layer framework accounting for the dominant geological groups, specifically the Coonambidgal Formation, upper and lower Shepparton Formations, Calivil Formation, the deeply weathered geology and the Palaeozoic basement. The grid resolution was 200m x 200m and as such this model has a finer spatial scale and more detail than the CSIRO Southern Riverine Plains groundwater model. Groundwater extraction data were provided by Goulburn-Murray Water. Whereas the groundwater model used in this study has been calibrated for the period 1990-2000, results reported hereafter are based on steady state solutions thereby representing the dynamic-equilibrium state in accord with the CSIRO Sustainable Yields project. The groundwater mass balance under current conditions is shown in Figure 31.

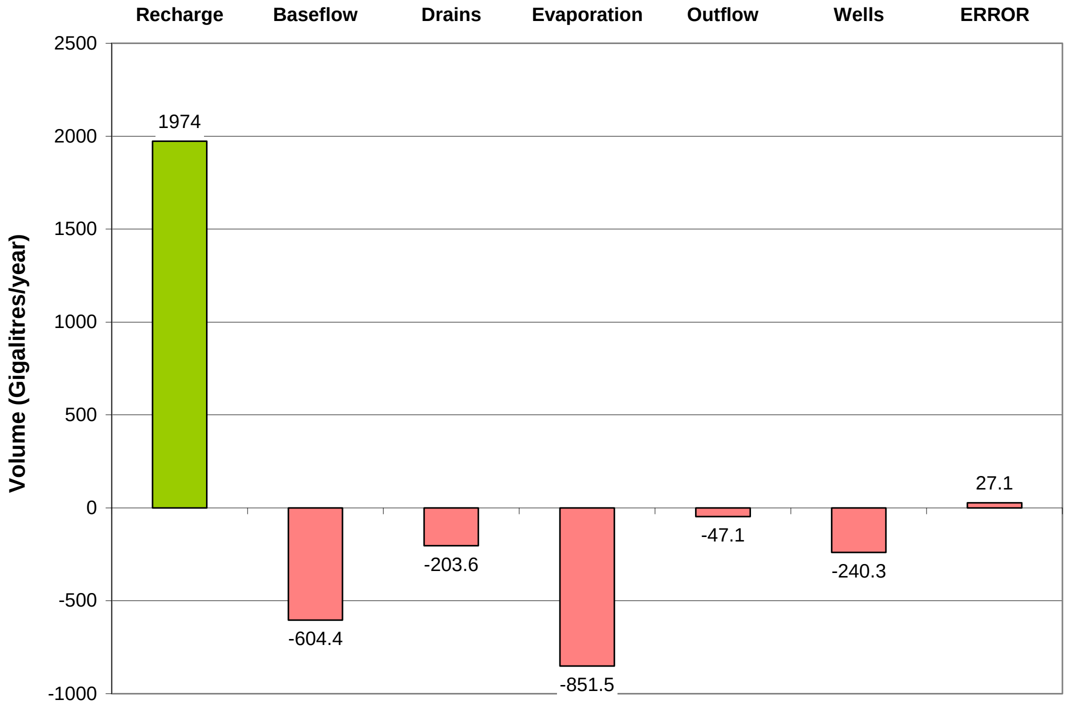


Figure 31 Groundwater mass balance under current conditions.

Spatial variation in groundwater recharge under differing climate change scenarios is presented in Figure 32 to Figure 34.

None of the focus local government areas are located within specified groundwater management areas (GMAs). In these local government focus areas most groundwater usage is associated with stock and domestic supply (rather than large scale abstraction). As a result, sustainable groundwater abstraction associated with reduction in groundwater recharge can not be determined accurately based upon the relatively small pumping volumes used (and not metered).

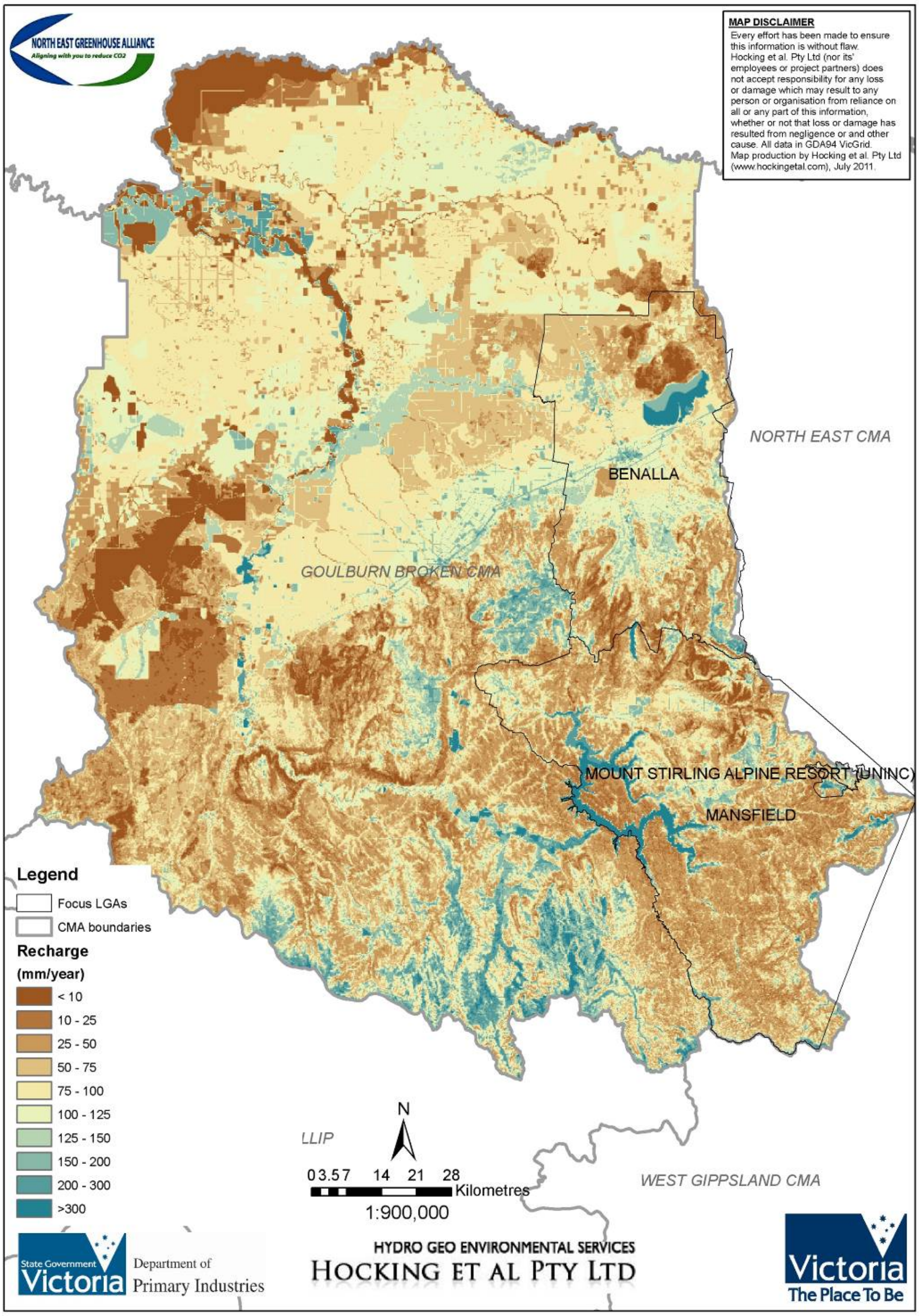


Figure 32 Mean annual groundwater recharge (mm/yr) under current conditions.

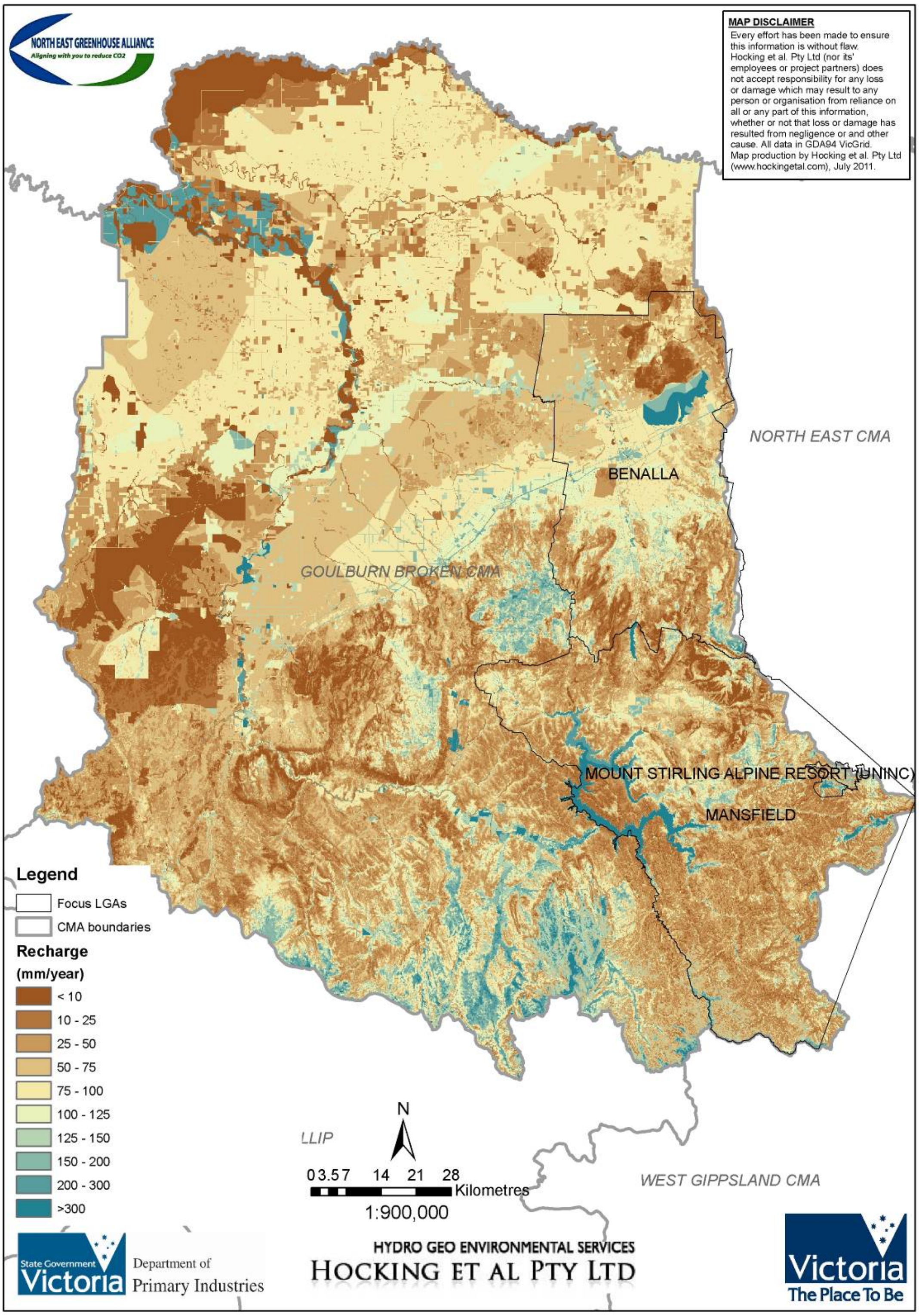


Figure 33 Mean annual groundwater recharge (mm/yr) under 2030 medium climate change conditions.

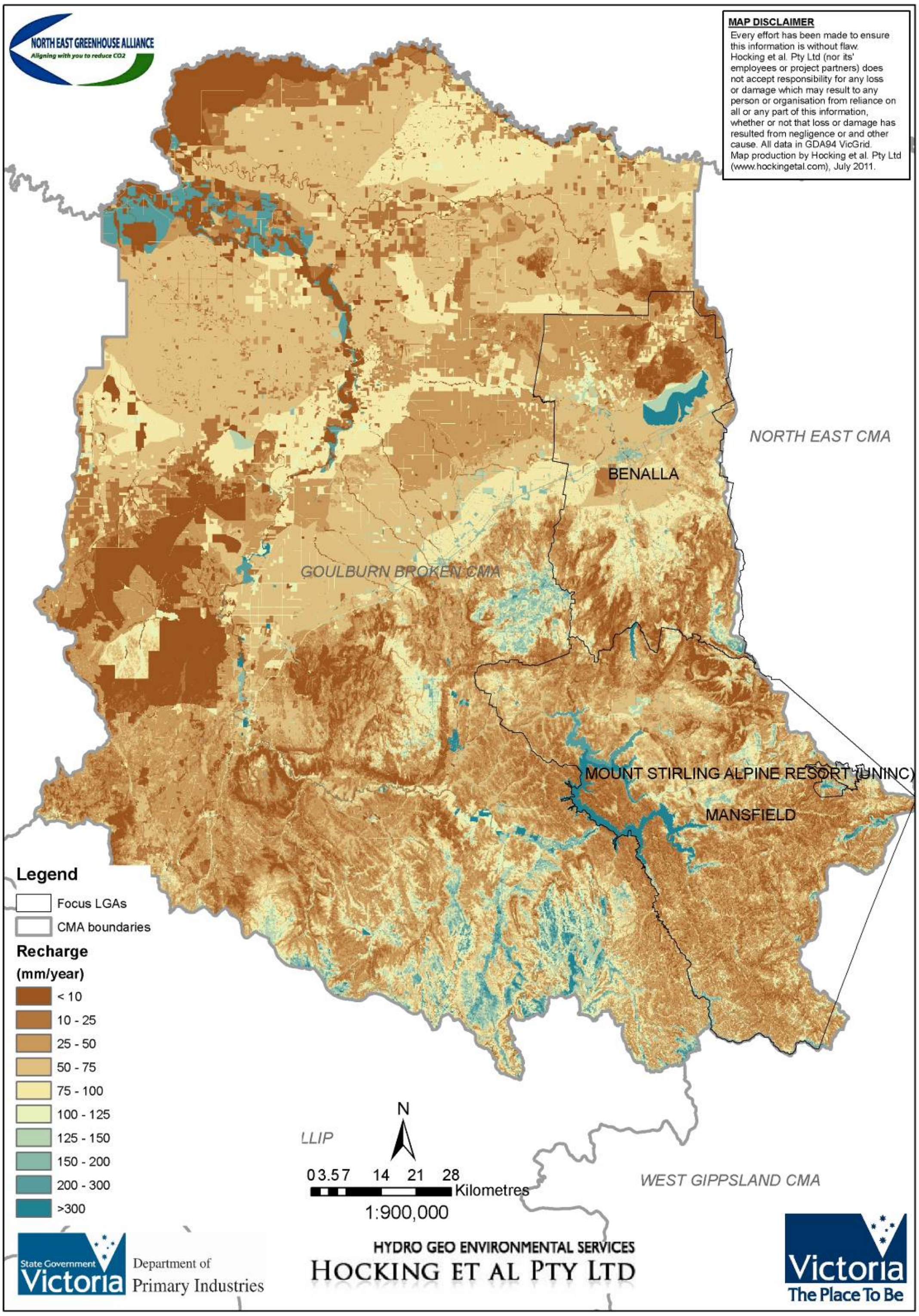


Figure 34 Mean annual groundwater recharge (mm/yr) under 2070 medium climate change conditions.

The change in total groundwater volume under different climate scenarios are summarised in Table 26 and Table 27 for the entire Goulburn Broken region and the focus LGAs respectively. The corresponding changes in groundwater elevation relative to current condition for each scenario are shown in Appendix B.

Table 26 Change in groundwater storage (GL) from current condition under various climate scenarios for the total Goulburn Broken CMA region.

Scenario	Change in groundwater storage from current
1995-2005	1414
2030 low	867
2030 med	1204
2030 high	1613
2070 low	1619
2070 med	2696
2070 high	4093

4.3.5 LGA groundwater response under climate change scenarios

Table 27 summarises change in groundwater storage in each focus LGA. Results suggest the Shire of Mansfield, Rural City of Benalla, and then the alpine resorts would have the greatest reduction in groundwater storage respectively. The significant volume variation is attributed the area of the LGA. That is, the Shire of Mansfield, Rural City of Benalla, then the alpine resorts has the largest to smallest areas respectively (refer to Appendix B for spatial information).

Table 27 Change in groundwater storage (GL) from current condition under various climate scenarios for focus Local Government Areas.

Scenario	Benalla Rural City	Mansfield Shire Council	Mount Hotham Alpine Resort	Mount Stirling Alpine Resort	Mount Buller Alpine Resort	Falls Creek Alpine Resort
1995-2005	-393	-938	-102	-4	-12	-32
2030 low	-217	-778	-35	-2	-7	3
2030 med	-331	-1124	-43	-4	-11	2
2030 high	-471	-1560	-52	-5	-17	0
2070 low	-471	-1561	-51	-5	-17	0
2070 med	-817	-2718	-79	-9	-31	-5
2070 high	-1251	-4278	-118	-14	-51	-15

5 COMPARATIVE RESULTS

This section summarises the predicted impacts of future climate on water resources within the North-East and parts of the Goulburn Broken region as reported in previous studies. In general, previous estimates have been broadly reported for the entire region which has limited the comparison to only consider CMA wide estimates. The locations of the LGA focus areas are located within both the North East and Goulburn Broken CMAs.

Table 28 summarises the seasonal impacts of future climate scenarios on rainfall and temperature range across the North-East CMA region relative to 1990 condition, whereas the Goulburn Broken has not been presented as it is less representative of the focus areas. This information is consistent with the spatially averaged impacts presented in Section 4.3. The corresponding likely climate change impacts on water balance components for the entire North-East CMA region are summarised in Table 29. A comparison of results suggests that the DPI estimates used in this review are within the limits reported by previous studies.

No other information is available to be compared with information derived for the focus local government areas as part of this exercise.

Table 28 CSIRO future seasonal climate projections for the North-East region

	2030	2070
Spring	Warmer by 0.3 to 1.6°C	Warmer by 0.8 to 5.0°C
	Precipitation decrease +3 to -15%	Precipitation decrease +10 to -40%
Summer	Warmer by 0.3 to 2.0°C	Warmer by 0.8 to 6.0°C
	Precipitation change uncertain +15 to -15%	Precipitation change uncertain +40 to -40%
Autumn	Warmer by 0.3 to 1.6°C	Warmer by 0.8 to 5.0°C
	Precipitation change uncertain +10 to -10%	Precipitation change uncertain +25 to -25%
Winter	Warmer by 0.2 to 1.4°C	Warmer by 0.7 to 4.3°C
	Precipitation decrease +3 to -10%	Precipitation decrease +10 to -25%

Table 29 Summary of annual climate change impacts derived from various studies (% deviation from historical)

Attribute	Report	Benchmark	Scenario	2030	2070
Average rainfall	DPI	relative to 1957-2004	High	-4	-9
	CSIRO	relative to 1990		-3	-10
Average temperature	CSIRO	relative to 1990		0.9	2.9
Potential evaporation	CSIRO	relative to 1990		3	9
Wind speed	CSIRO	relative to 1990		-1	-2
Relative humidity	CSIRO	relative to 1990		-0.6	-2
Solar radiation	CSIRO	relative to 1990		0.7	2.2
Runoff – entire region	DPI	relative to 1957-2004	High	-8	-17
	CSIRO	relative to 1990		0 to -20	0 to >-20
Total quick flow – entire region	DPI	relative to 1957-2004	High	-8	-17
Total inflows to Murray system	NRSWS	relative to 1990	Low	5	~ 8
	NRSWS	relative to 1990	Medium	-10	~-21
	NRSWS	relative to 1990	High	-20	~-40

6 CONCLUDING COMMENTS

Data analysis undertaken as part of this exercise has completed all LGAs within the North East CMA and parts of the eastern flanks of the Goulburn Broken CMA. Many conclusions derived as part of the previous report (Beverly and Hocking, 2010) remain relevant within this document.

No previous climate change studies consider the entire North-East or Goulburn Broken CMA regions with sufficient spatial resolution to address the project objectives. Typically previous studies focused on key river basins such as the Kiewa and Ovens river systems. Additionally previous studies adopted future projections which did consider both the 2030 and 2070 climate change scenarios. Given these limitations this review deployed a methodology developed by project partners to downscale climate pattern of change estimates and subsequently modelled the impact of climate change on water availability within the CMA region using a suite of physically based farming system models and a fully distributed multi-layered groundwater model. The adopted methodology presented in this report is shown to offer finer scale, CMA wide regional estimates across a range of designated future climate scenarios.

Key findings from this study are broadly aligned to climate change scenarios previously assessed and reported with the general observation that:

1. Under future climate water supplies will be less reliable
2. Groundwater levels are expected to decline due to reduced recharge and increased extractions
3. River and wetland biodiversity will be stressed and likely to decline
4. Water quality is likely to decline
5. Duration and intensity of snowfall is likely to decrease

Specific conclusions from this study are:

10. Data analysis suggests that LGAs located in the snowfields would expect minor reductions in rainfall but notable increases in average temperature, these increases in temperature are likely to reduce to duration and depth of snow in these locations. Mt Buller, Mt Stirling, Mt Hotham and Falls Creek are most likely to observe the greatest to least increase in temperature respectively under climate change.
11. The greatest falls in groundwater level and storage were identified to occur in Mansfield Shire Council, which is likely to be attributed to the majority of the LGA being located upon basement geology and native vegetation cover.
12. Large uncertainties are associated with climate change predictions, both at the point scale and catchment scale. These uncertainties are introduced due to variability in the underpinning data, simulation model constructs and assumptions adopted with model applications.
13. Significant variations in climate change impacts on water availability have been previously reported, and in some cases contrast the predictions derived in this study.

This reinforces the degree of uncertainties associated with the derivation of the hydrological impact of future climate scenarios.

14. Under the low 2030 climate condition runoff would be reduced by between 2% and 16% depending upon landscape position and dynamics. In order of increasing impact, Mount Hotham Alpine Resort would be least impacted (-2%) followed by Falls Creek Alpine Resort (-2%), then Mount Stirling Alpine Resort (-4%), Rural City of Benalla (-4%), Shire of Mansfield (-8%) and Mount Buller Alpine Resort (-16%).
15. Under the dry extreme 2030 climate condition runoff would be reduced by between 10% and 35% across the LGAs. In order of increasing impact, Mount Hotham Alpine Resort would be least impacted (-10%) followed by Falls Creek Alpine Resort (-11%), Benalla Rural City (-20%), Mount Stirling Alpine Resort (-23%), Mansfield Shire Council (-25%) and Mount Buller Alpine Resort (-35%).
16. Under the low 2070 climate condition flows would be reduced to approximately those predicted under the dry extreme 2030 climate conditions with reductions ranging between 10% and 35%.
17. Under the dry extreme 2070 climate condition flows would be reduced across the LGAs by between 34% and 72%. In order of increasing impact, Mount Hotham Alpine Resort would be least impacted (-34%) followed by Falls Creek Alpine Resort (-37%), Mount Stirling Alpine Resort (-39%), Benalla Rural City (-67%), Mansfield Shire Council (-71%) and Mount Buller Alpine Resort (-72%)
18. An understanding of landscape dynamics is critical in estimating the impact of climate change on water availability, productivity and groundwater sustainability.

On the basis that the IPCC original climate change projections have been revised, this study recommends undertaking more detailed modelling using the recently updated CCAM Mark 3.6 pattern of change data from CSIRO. Enhancement of the existing groundwater model to better capture temporal groundwater dynamics and sustainable extraction limits has also been identified as a key recommendation.

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Appendix A – Spatial data layers

This Appendix presents key spatial data sets that underpin the analysis used to estimate current and future water resources within the North-East region.

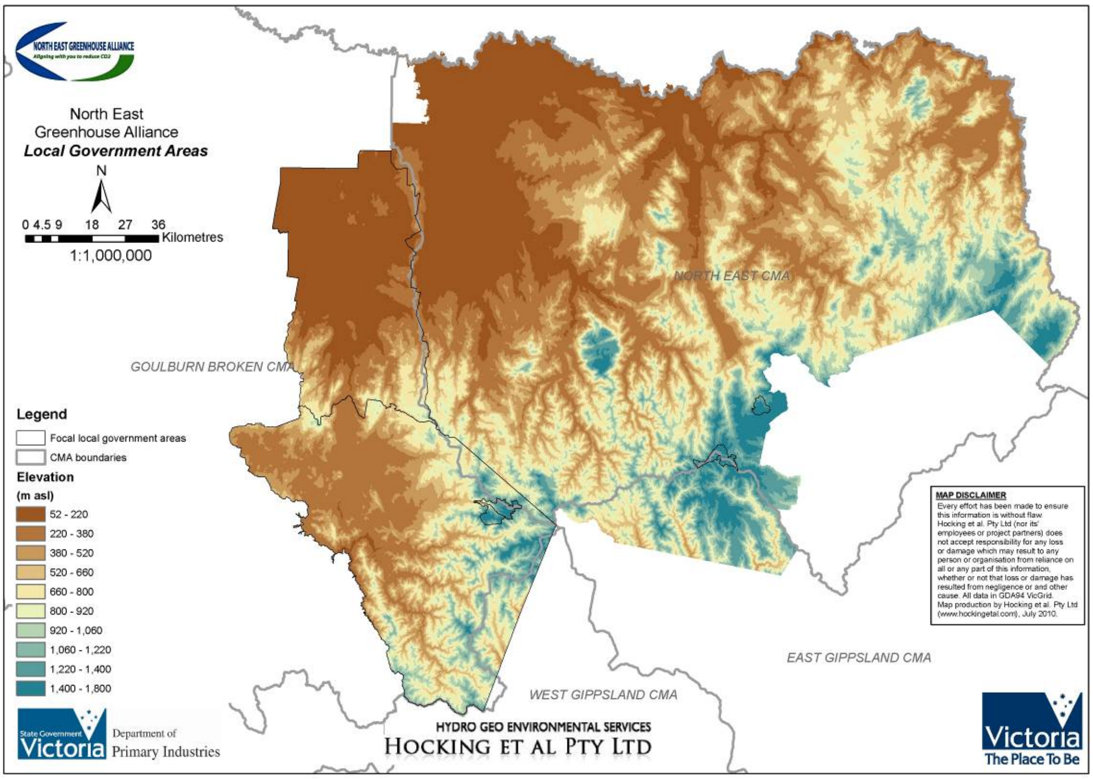


Figure A.1. Elevation (metres above sea level)

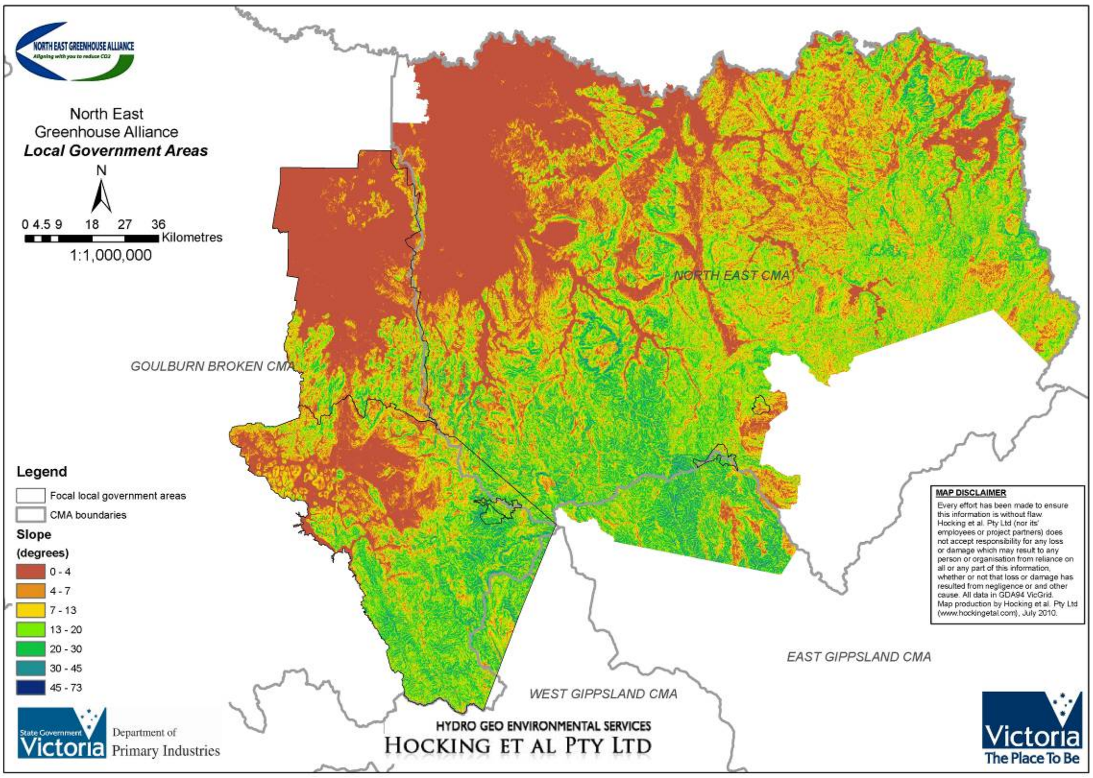


Figure A.2. Slope in degrees.

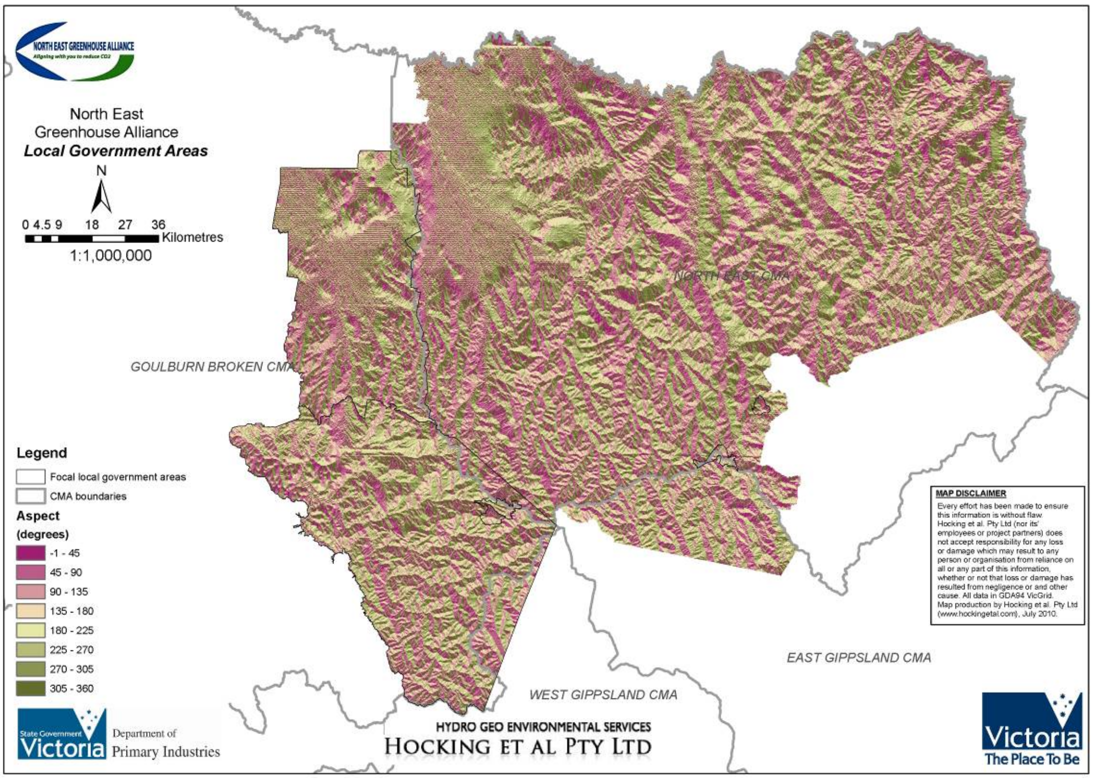


Figure A.3. Aspect in degrees.

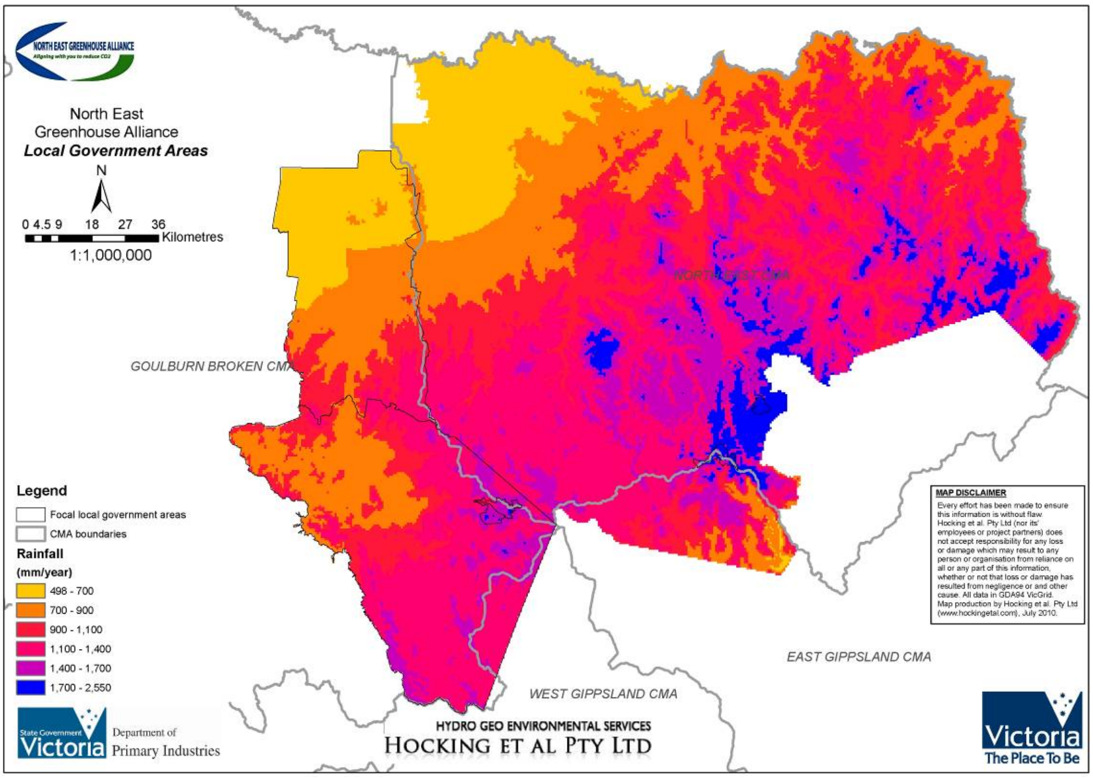


Figure A.4. Mean annual rainfall (mm/yr) for the period 1957-2005.

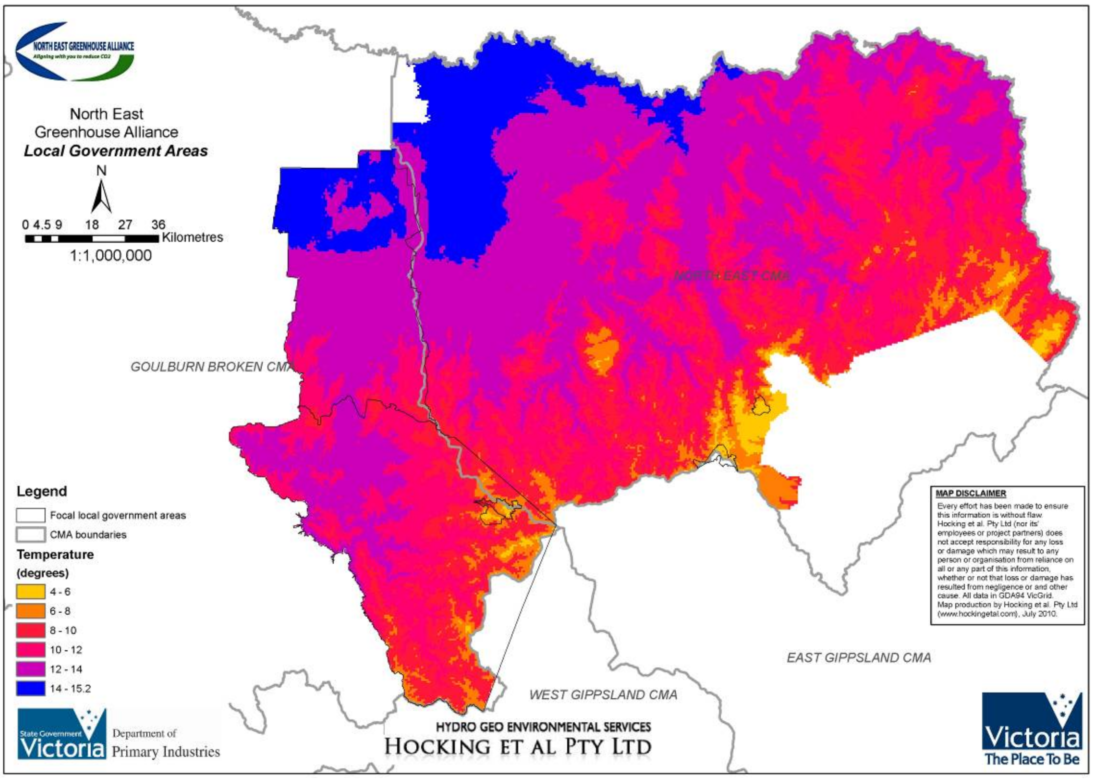


Figure A.5. Average daily temperature (oC) for the period 1957-2005.

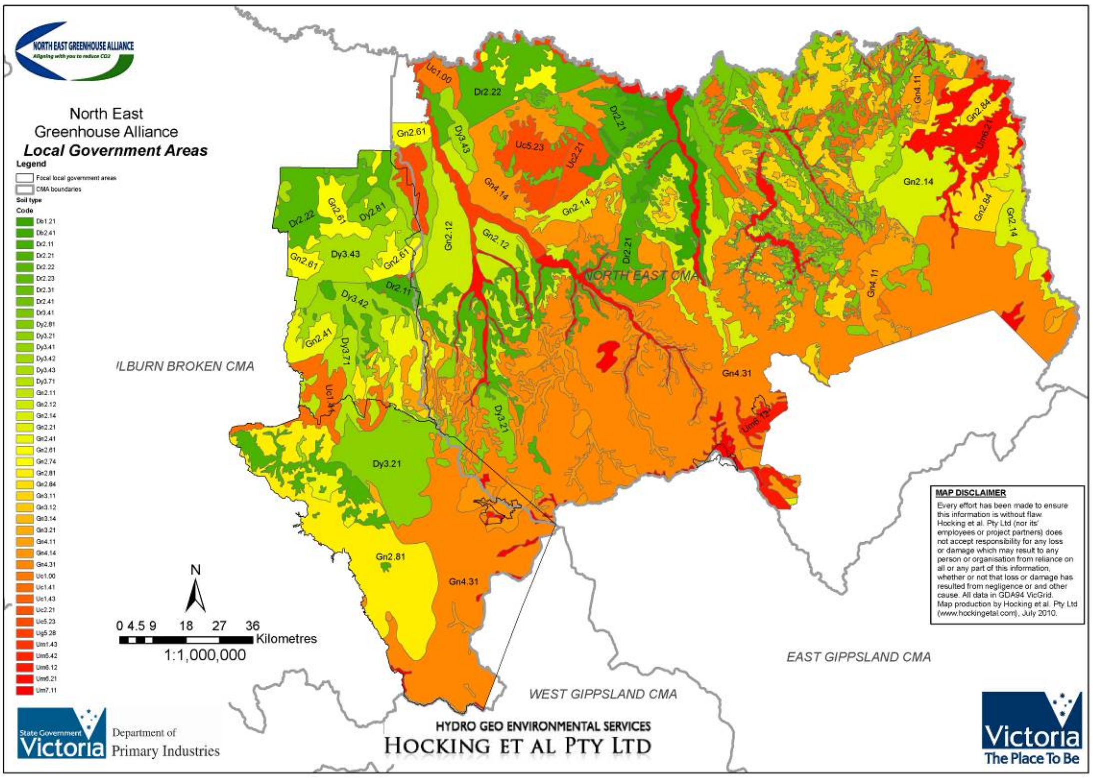
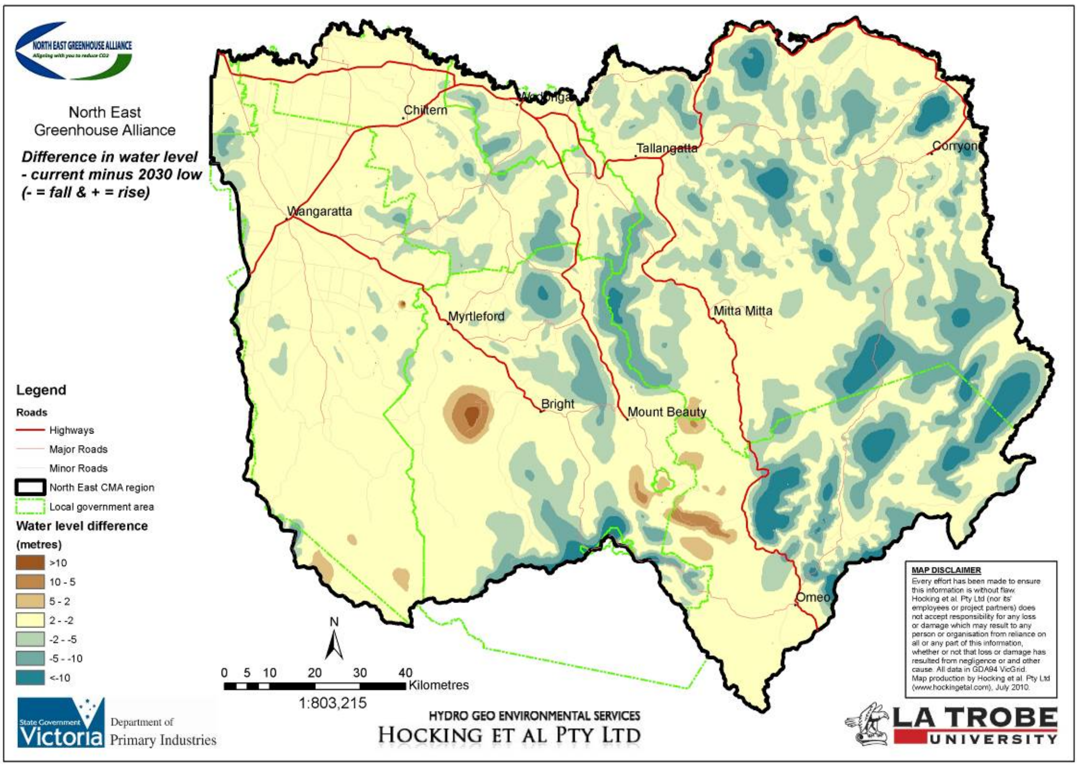


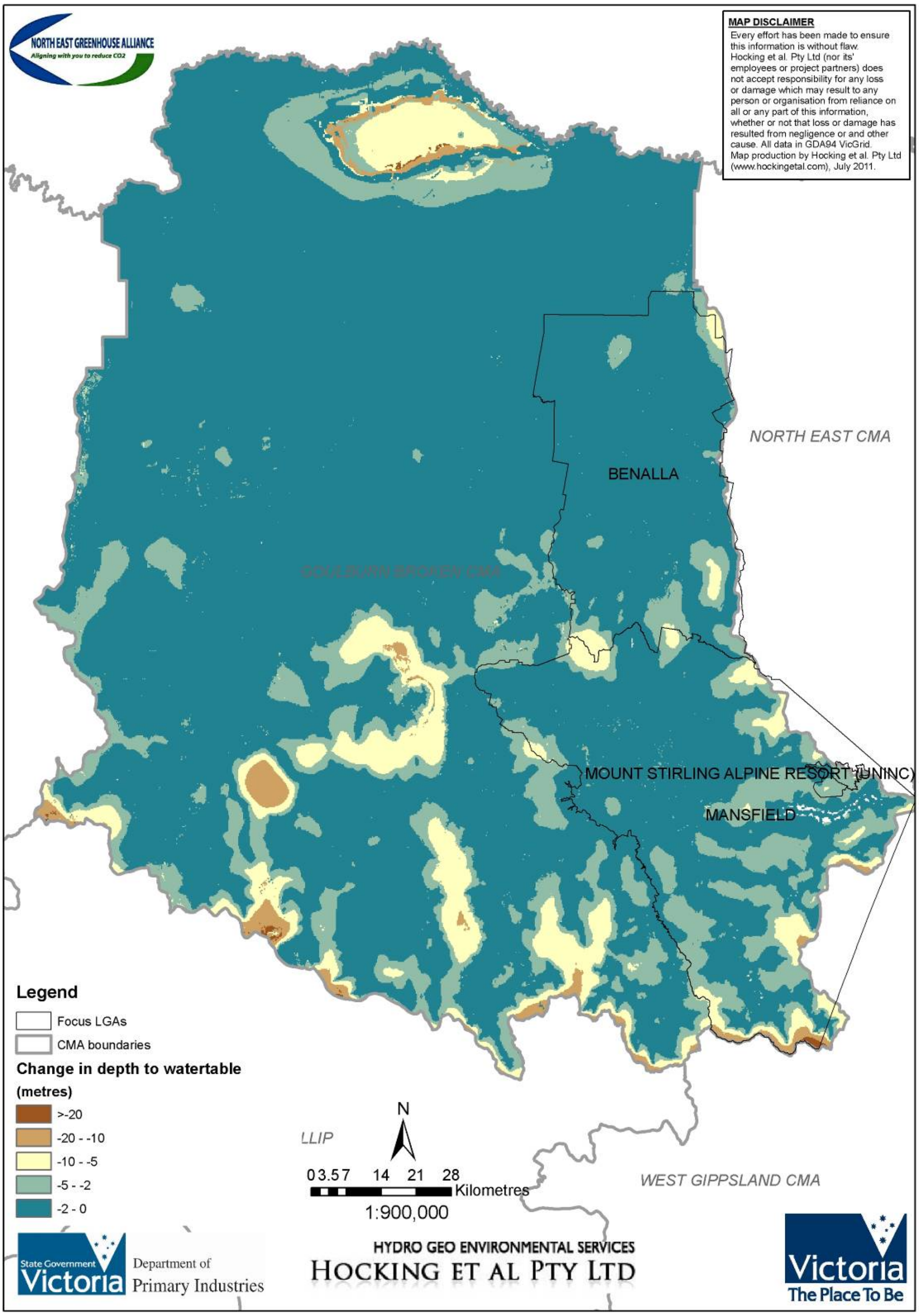
Figure A.6. Soil type classified to Northcote coding.

Appendix B – Simulated water level change

Maps below present the anticipated water level change for the North East and Goulburn Broken CMAs under differing climate change scenarios.

Watertable elevation from current condition to 2030 low climate scenario




NORTH EAST GREENHOUSE ALLIANCE
Aligning with you to reduce CO2
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NORTH EAST CMA
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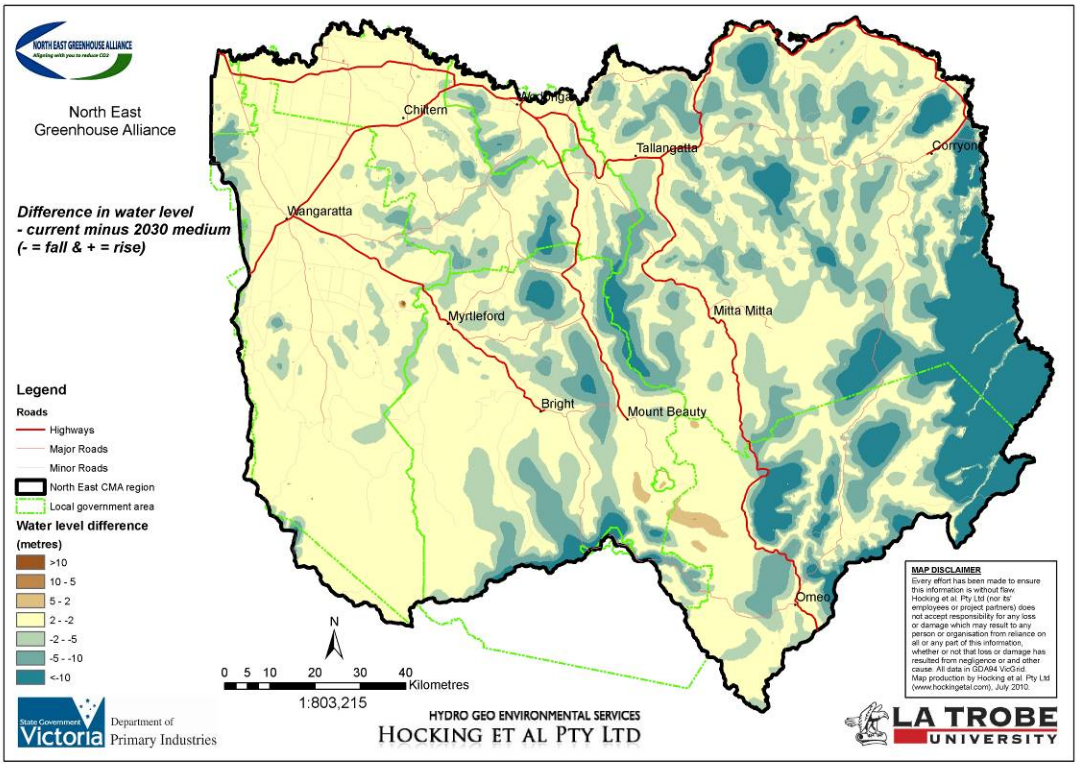
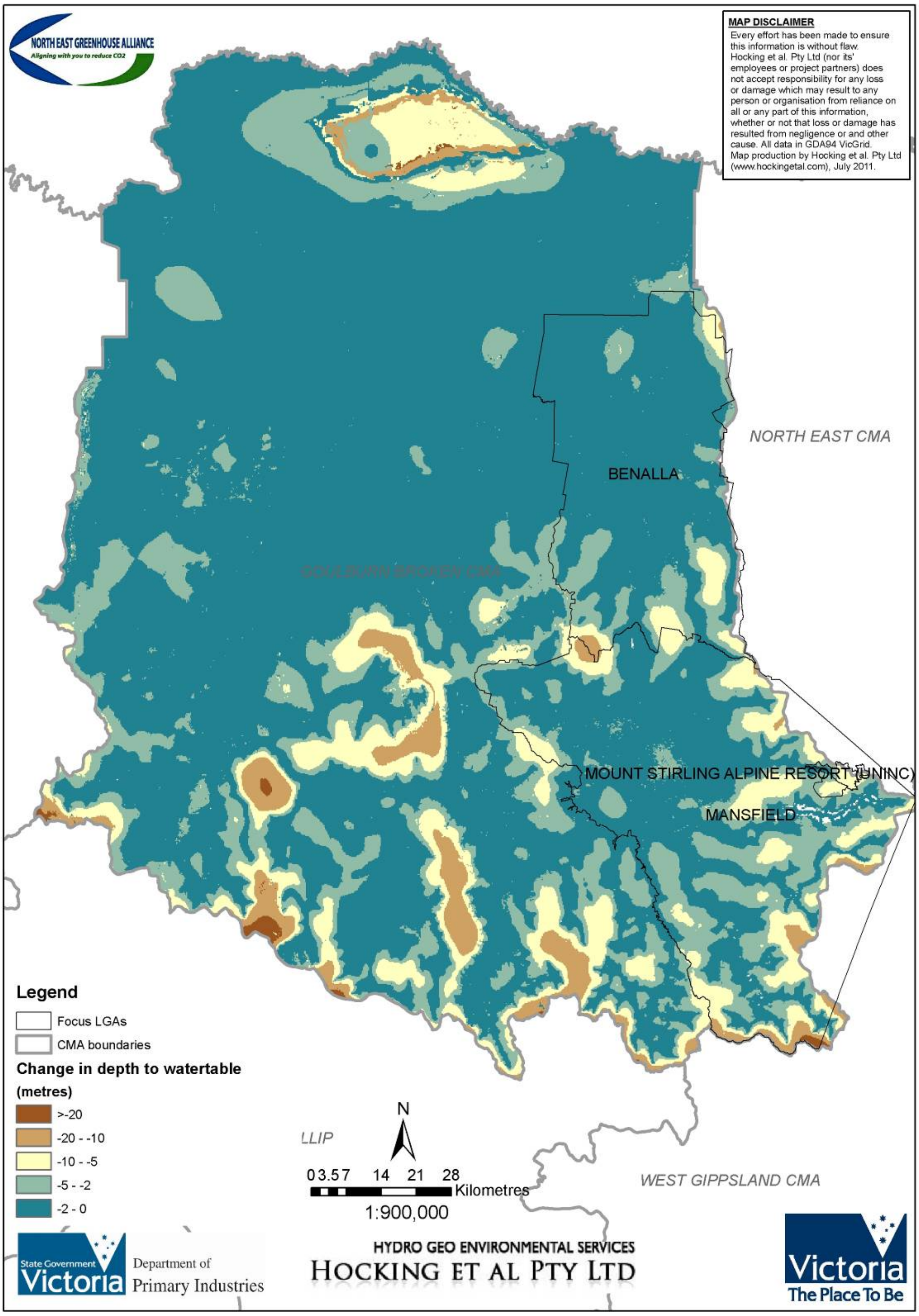
Watertable elevation from current condition to 2030 medium climate scenario

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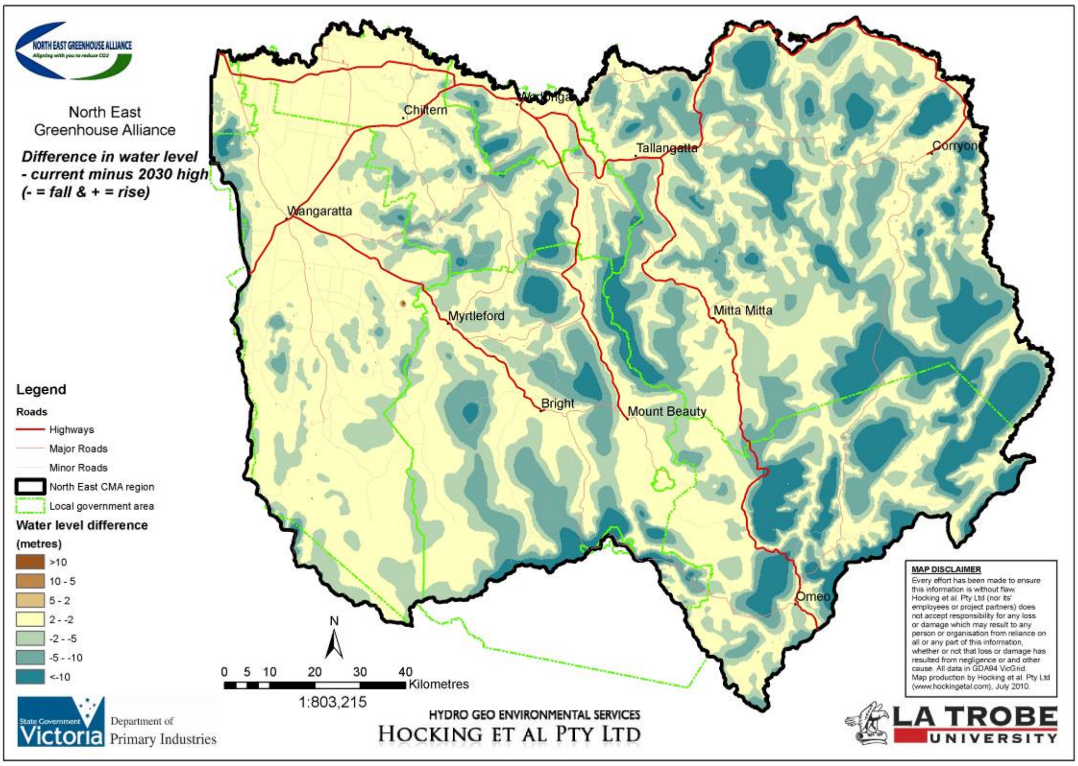
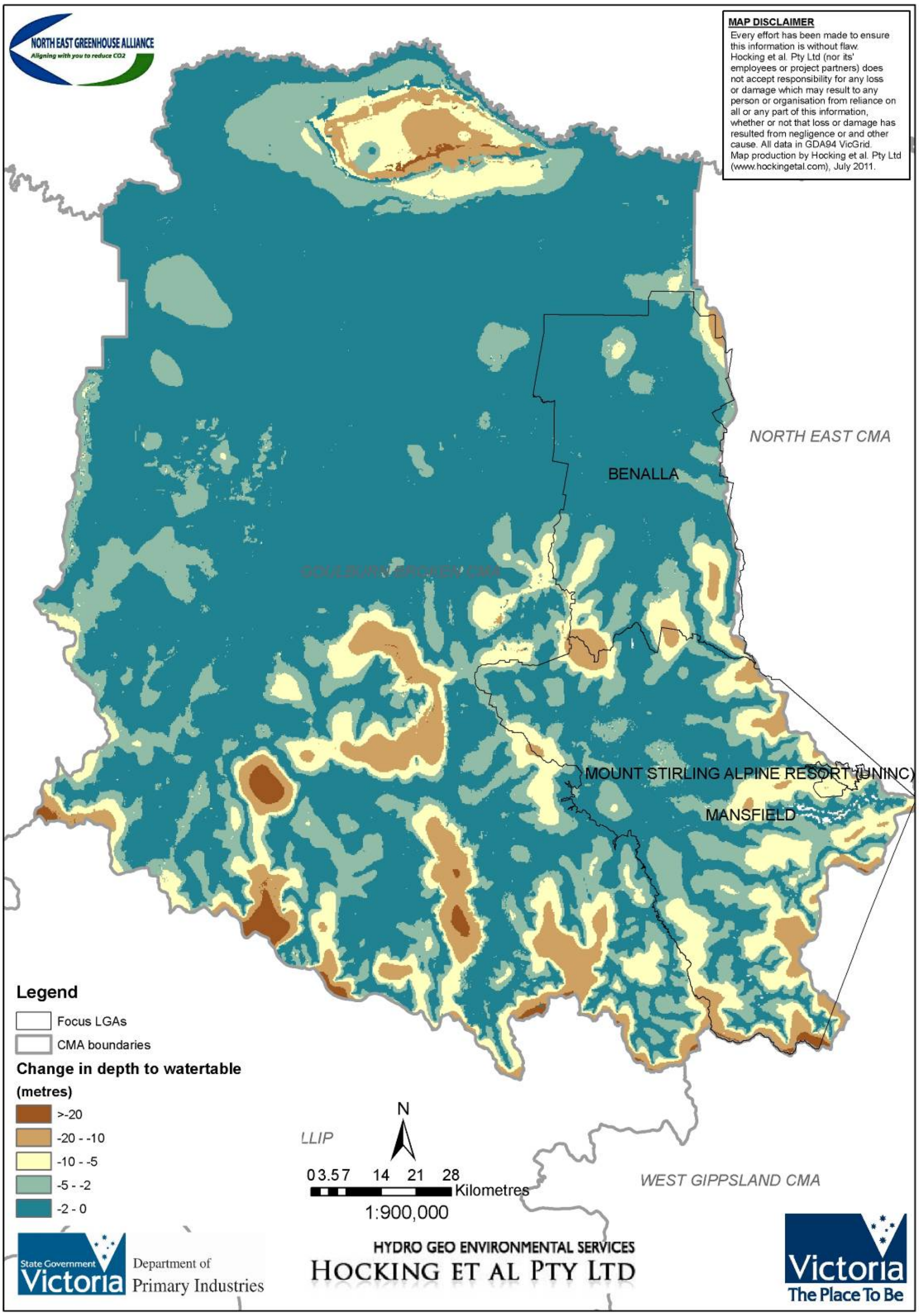
Watertable elevation from current condition to 2030 high climate scenario

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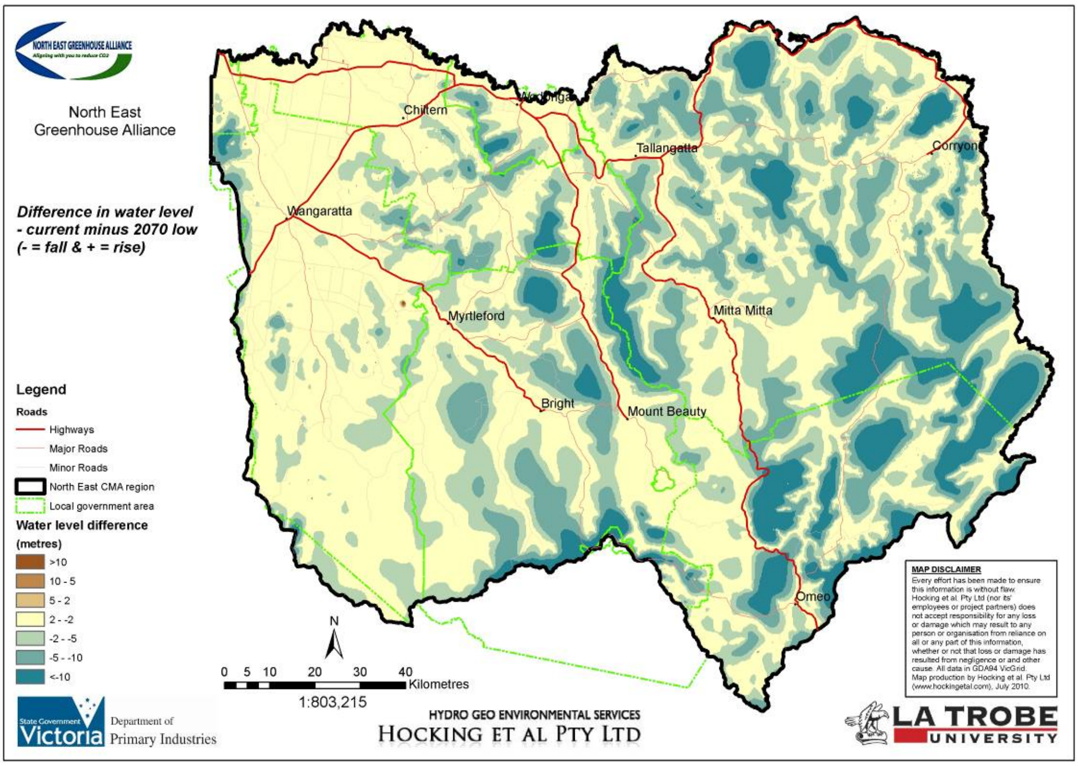
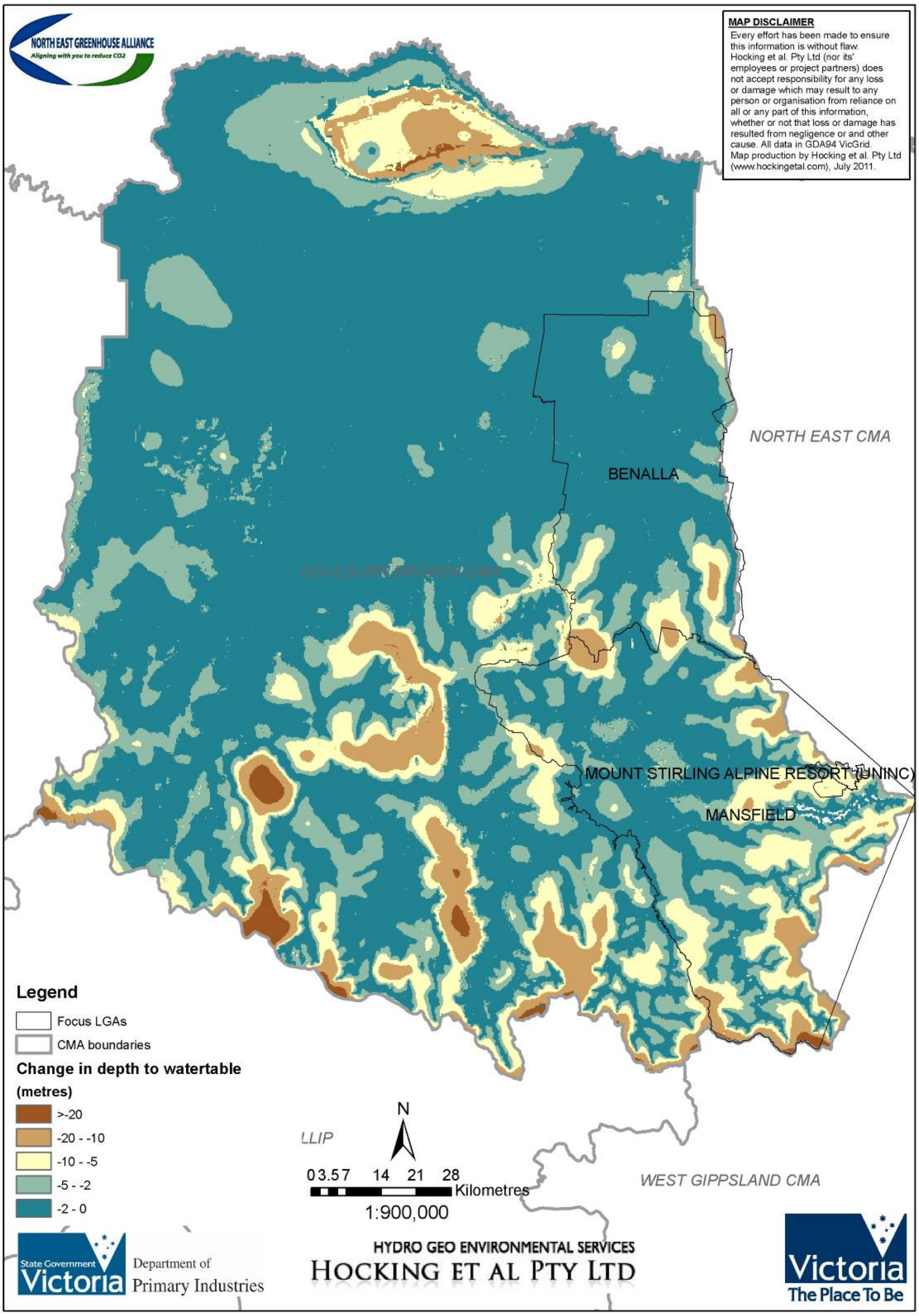
Watertable elevation from current condition to 2070 low climate scenario

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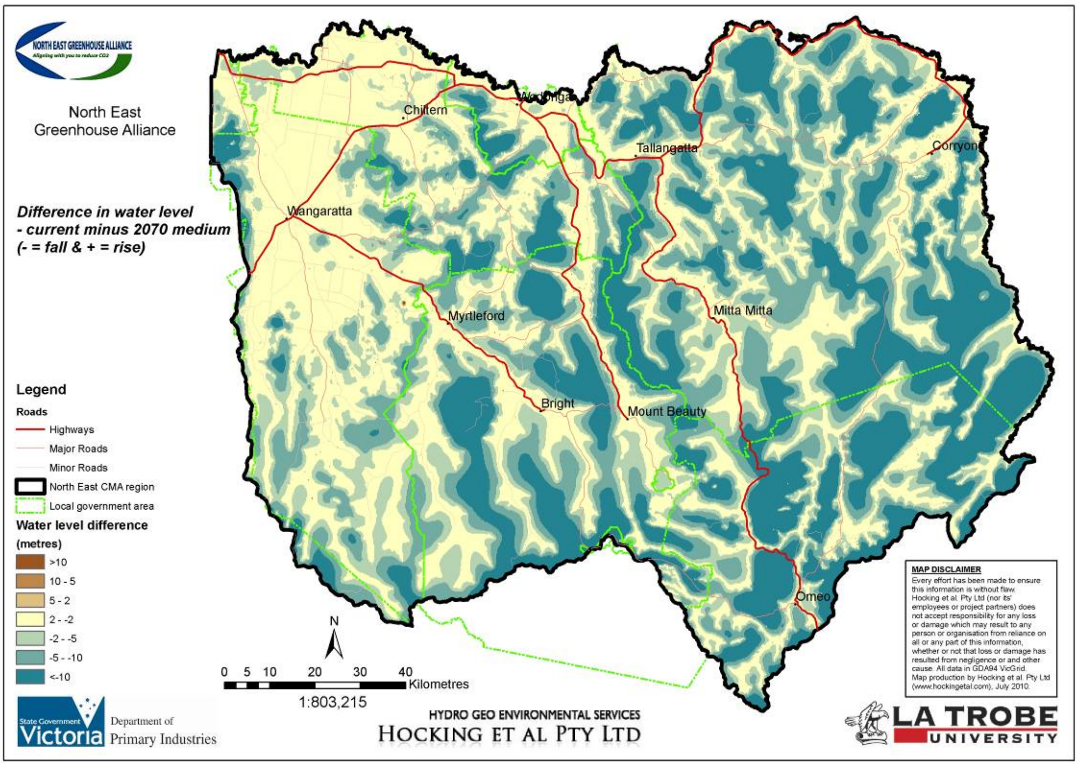

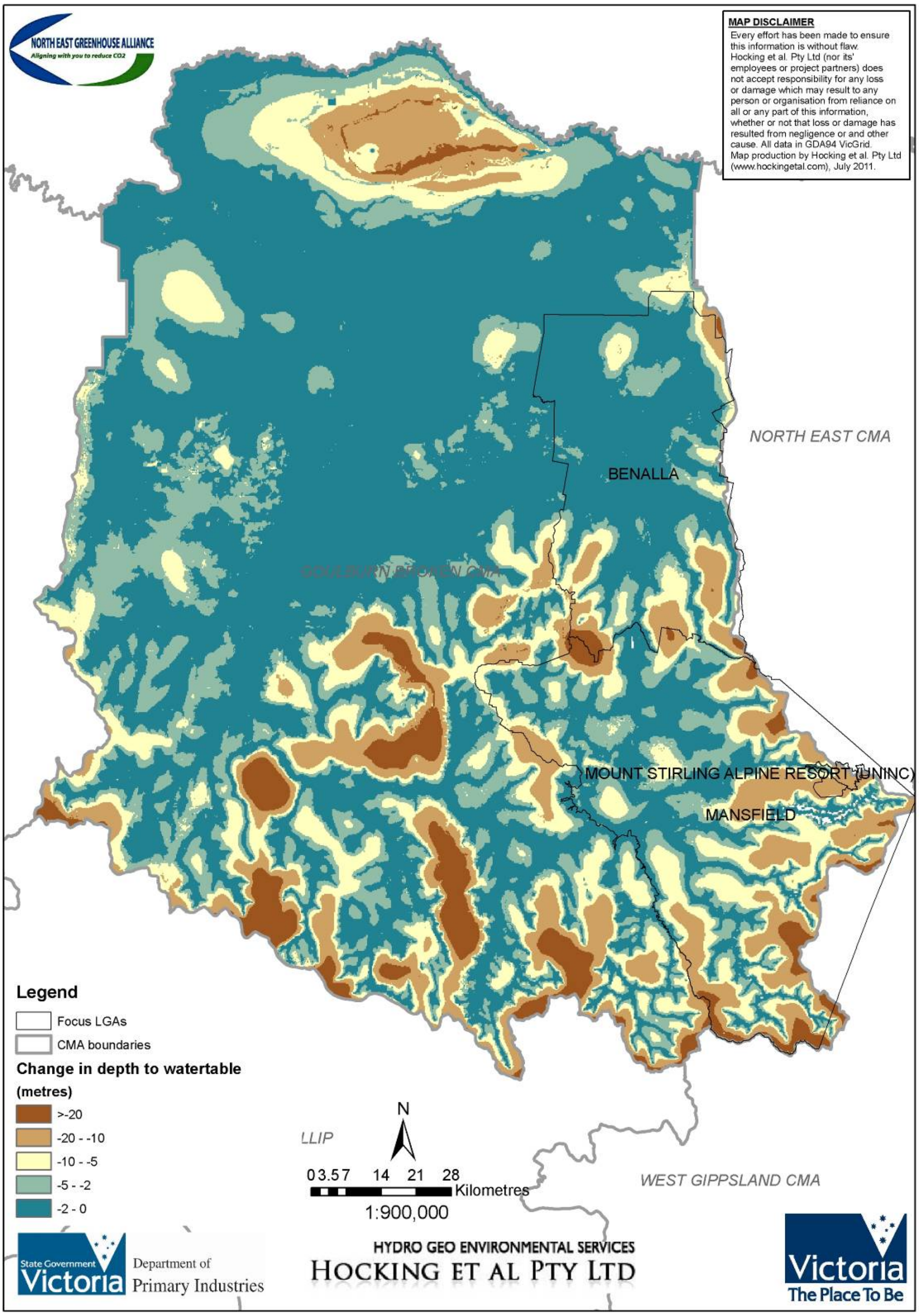
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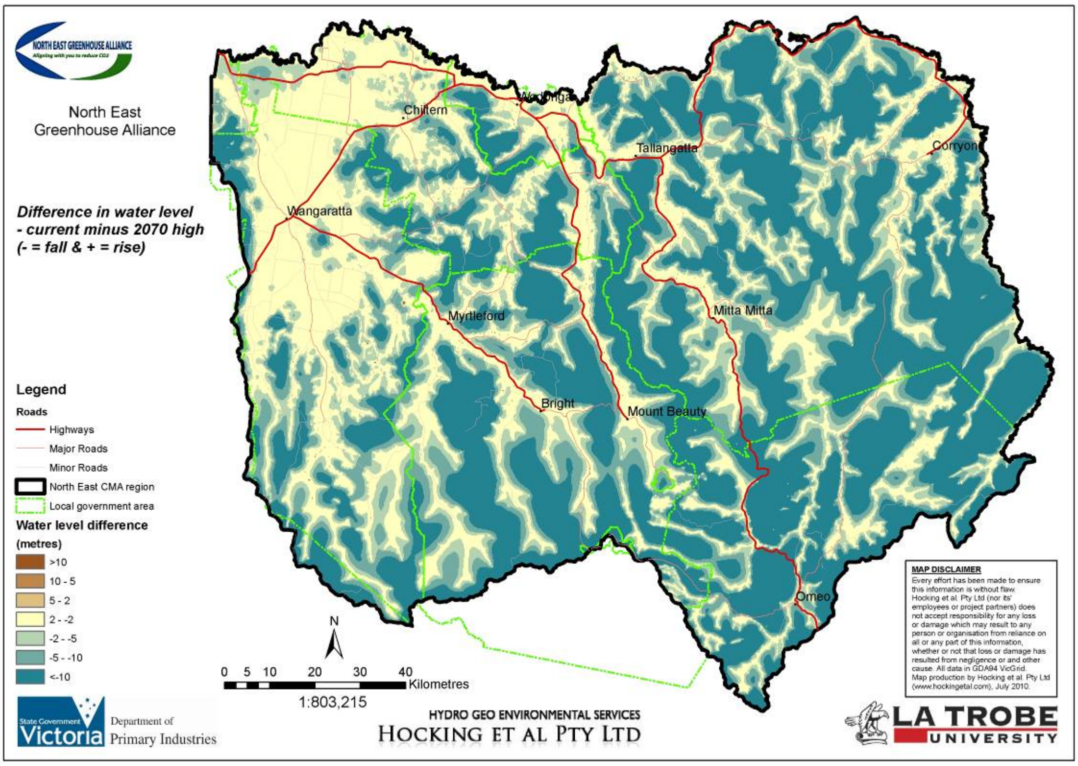

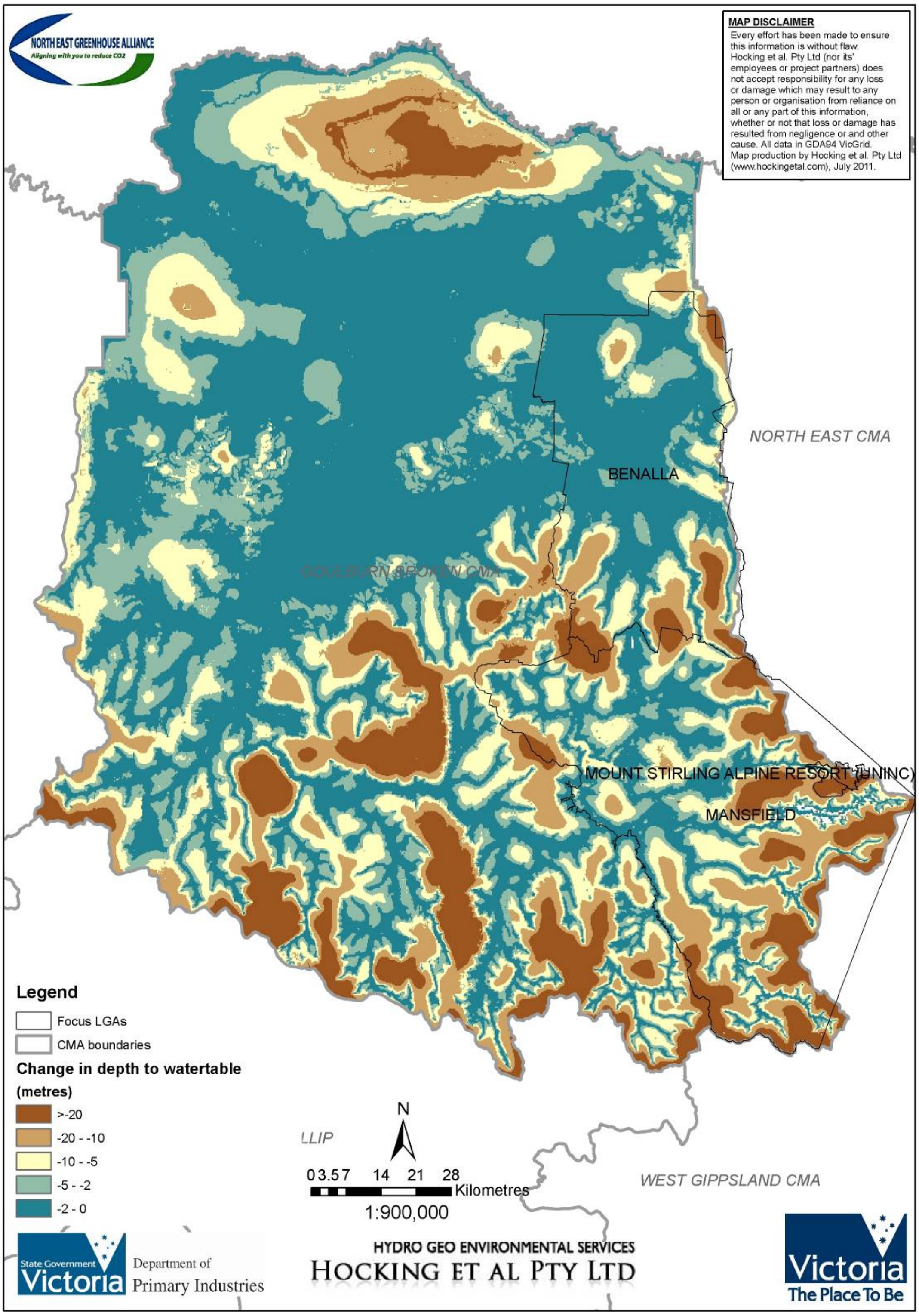
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