Appendix 6. Impacts of climate change to 2070 at eight locations across southern New South Wales: a preliminary analysis

Introduction

As part of the *Southern Livestock Adaptation 2030* program, the NSW Department of Industry & Investment (NSW I&I) has been using the GRAZPLAN simulation models to analyse the impacts of likely future climate change on a wide range of grazing systems, and also to explore possible options for adapting to these changes. The focus of I&I's work is on the relatively near term (i.e. climates projected for the year 2030). The brief of *Southern Livestock Adaptation 2030*, however, includes a requirement to consider climate changes over longer time frames (out to the year 2070).

This study uses simulation modelling to examine the likely impact of projected changes in climate and atmospheric CO_2 concentration at 2030, 2050 and 2070 on the dynamics of pastures across eight locations in southern New South Wales. Impacts on profitability (at constant prices) and on three important natural resource indicators (ground cover, deep drainage & livestock methane production) are considered. Adaptations to changing climate are limited to modification of stocking rates.

Methods

The GRAZPLAN simulation models of the dynamics of grazed temperate grasslands (Freer *et al.* 1997; Moore *et al.* 1997) were used in this study. These models are widely employed within Australia for purposes of research (e.g. Cayley *et al.* 1998; Clark *et al.* 2003; Mokany *et al.* 2010) and also in decision support for producers (Donnelly *et al.* 2002 and references therein; Warn *et al.* 2006).

The models' behaviour will respond to changes in climate and atmospheric CO_2 concentration in a variety of different ways. The GRAZPLAN accounts for four effects of increasing CO_2 concentration: reduced transpiration due to partial stomatal

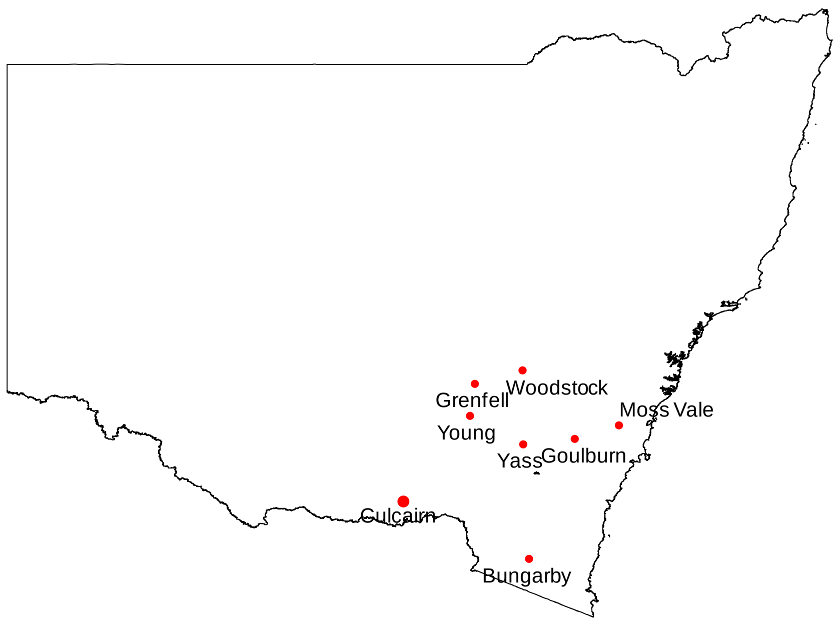

Figure A6.1. Map of the eight locations in southern NSW at which climate change impact simulations were carried out.

closure, a direct CO_2 fertilization effect, decreases in specific leaf area and decrease in leaf nitrogen content. Changes in rainfall at a location will mainly affect the dynamics of the models via the water balance. Effects of changes in soil water content on pasture growth rate and the decomposition of litter are represented in the pasture model. The key effects of increasing temperatures across southern Australia – at least for increases up to about 3°C – are also accounted for by model equations describing effects of increased temperatures on vapour pressure deficit, seed dormancy release, germination, plant phenology, rates of assimilation, respiration and decline in the digestibility of herbage (Moore et al. 1997), reductions in animal intakes on hot days, decreased energy expenditures by livestock in winter and lower peri-natal mortality of lambs (Freer et al. 1997). In the GRAZPLAN models, livestock methane emissions are predicted following Blaxter & Clapperton (1965).

Eight locations where NSW I&I officers have been carrying out climate change studies were selected for analysis (Figure A6.1). Annual rainfall at the locations ranges from medium (550 mm) to high (950 mm) and average annual temperature from a cold 11.5°C to a temperate 16.0°C (Table A6.1). For each of these eight locations, a set of representative grazing systems (soils, pastures, livestock, management and financial data) has been described as part of the NSW I&I *Southern Livestock Adaptation 2030* project. One representative grazing system per location was chosen for use in this study, and the input data required to simulate that grazing system with the GrassGro decision support tool (which implements the GRAZPLAN models) were provided by NSW I&I.

Details of the representative farms are given in Table A6.1. Sheep enterprises were selected where available (at 6 of the 8 locations) to keep the simulations as consistent as possible, but a high degree of diversity in animal and pasture genotypes and management practices was inevitably included.

A reference period of historical weather data (1970-1999) was simulated, plus projected future climates under the SRES A2 emissions scenario for the years 2030, 2050 and 2070. In order to take account of the uncertainty in projected climates, climate predictions from four global circulation models (GCMs) were considered for each future year: UKMO-HadGEM1 (Johns *et al.* 2006), CCSM3 (Collins *et al.* 2006), ECHAM5/MPI-OM (Roeckner *et al.* 2003) and GFDL-CM2.1 (Delworth *et al.* 2006). 13 climates (one historical and 12 projected futures) were therefore considered at each location.

Daily weather data sequences for each projected climate were constructed using a downscaling technique adapted from that of Zhang (2007). Briefly, the technique uses ranked monthly values from the historical weather record and outputs from a global circulation model to develop a locally-specific “transfer function” that maps the GCM-predicted monthly value to a location-specific monthly value. The resulting time sequences of monthly weather values are detrended when a weather sequence corresponding to the climate for a particular time is required, as in this study. Finally, a stochastic weather generator (Hansen and Mavromatis 2001) is used to convert the monthly time course of weather to daily values. Full details of the technique are given by Moore (2008). ISAM reference atmospheric CO_2 concentrations (Houghton *et al.* 2001) corresponding to the A2 scenario for each date were used (350 ppm for historical climate, 451 ppm for 2030, 532 ppm for 2050 and 635 ppm for 2070).

GrassGro (version 3.2.2) was used to carry out a simulation experiment with the following factors: location (8) x climate (13) x stocking rate (11-16 levels depending on the location). Four replicates of each combination of factors were simulated to reduce the small effects of random births & deaths on the flock/herd age structure.

Table A6.1. Attributes of the grazing systems that were analysed with the GRAZPLAN models at each of eight locations across southern NSW. PAWC = plant-available water-holding capacity

Location	Mean Annual Rainfall (mm)	Mean Annual Temperature (°C)	Soil	PAWC (mm)	Pasture species	Grazing enterprise	Lambing/ Calving Date
Bungarby	550	11.5	Stony chocolate soil of basaltic origin	119	*Poa sieberiana* *Austrostipa* spp. Annual legumes	Self-replacing Merino ewes, lambs sold at 14 months	16 Sep
Moss Vale	953	13.2	Yellow-grey duplex soil	195	Cocksfoot Perennial ryegrass White clover	British x Charolais cows, weaners sold at 9½ months	11 Aug
Goulburn	647	13.3	Shallow yellow-grey duplex soil	67	Phalaris Annual grass Subterranean clover	Self-replacing Merino ewes, lambs sold at 15 months	31 Aug
Yass	697	13.9	Sandy loam over heavy clay	113	Annual grass Subterranean clover	Self-replacing Merino ewes, lambs sold at 15 months	31 Aug
Woodstock	753	14.4	Light-textured brown chromosol	198	Phalaris Subterranean clover	First-cross ewes, lambs sold at 44 kg	12 Mar
Young (2-paddock system)	680	14.8	Gradational earth	114 162	60 % Annual grass Subterranean clover 40% Lucerne Annual grass	Angus cows, yearlings sold at 350-360 kg	11 Jul
Culcairn	616	15.3	Red duplex soil, hard-setting A horizon	105	Annual grass Subterranean clover	First-cross ewes, lambs sold at 6½-7½ months	28 Apr
Grenfell	641	16.0	Red duplex soil, hard-setting A horizon	120	Phalaris Annual grass Subterranean clover	Self-replacing Merino ewes, lambs sold at 5 months	20 Jul

Table A6.2. Costs and prices used to calculate financial returns. DW = dressed weight; LW = live weight

Enterprise		Fine-wool Merino			Medium-wool Merino & crossbred ewes	Cattle	
Location		Bungarby	Goulburn	Yass	Young, Woodstock, Culcairn	Moss Vale	Grenfell
Prices for:							
Female young stock		60.00 /head	35.00 /head	35.00 /head	3.61 /kg DW	1.98 /kg LW	1.68 - 2.02 /kg LW*
Male young stock		1.50 /kg LW	35.00 /head	35.00 /head	3.61 /kg DW	2.10 /kg LW	1.78 - 2.14 /kg LW*
Cull stock		3.00 /kg DW	1.80 /kg DW	1.80 /kg DW	1.82 /kg DW	1.27 /kg LW	1.30 /kg LW
Dressing percentage		42%	41%	41%	41%		
Skin price		1.00	5.00	5.00	5.00		
Wool price:	18 µ		1076		1130		
(¢/kg clean)	19 µ		976		977		
	20 µ		885		840		
	22 µ		838		762		
	23 µ				738		
	25 µ				695		
	27 µ				492		
	29 µ				462		
Average:fleece price			0.90		0.90		
Cost of shearing ($)			5.74		5.74		
Cost of wool sales			4%		4%		
Husbandry costs ($/yr):							
Adult stock			3.40		3.40	17.00	
Young stock			4.50		4.50	12.00	
Purchase costs ($):							
Ewes or cows			n/a		Merino 60 Crossbred 90	1000	
Rams or bulls		1200	800	800	800	4500	
Fixed cost of sales		3.00	2.00	2.00	2.00	37.00	
Variable cost of sales			5%		5%	5%	
Cost of maintenance supplement (¢/MJ)			2.5		Young 2.1 Woodstock 1.8 Culcairn 2.7	2.8	1.0

* Cattle prices at Grenfell vary by month

For each simulation, physical and financial outputs (rainfall, temperature, pasture growth rates and composition, conception and weaning rates, quantities of wool and livestock sales and amounts of supplementary feeding, income from wool and meat sales and costs associated with sales, animal husbandry, supplementary feeding and pasture management, ground cover, methane emissions and deep drainage) were recorded. Costs and prices used to compute economic returns are given in Table A6.2. A long-term rate of profit was calculated as the gross margin less $100/ha overheads and a further adjustment for the capital cost of the livestock required at each stocking rate (a 7% interest rate was assumed).

Within each location x climate combination, an “optimal sustainable” stocking rate was then identified as that rate which maximized long-term profit, subject to the constraint that ground cover (averaged over the farm) should be less than 0.70 on no more than 7% of days over a 30-year period. The sustainable optimal stocking rate was identified by interpolating between the gross margins and ground cover indices resulting from the simulations at each level of stocking rate. All results are presented at this stocking rate.

Results

Key indices describing the production and NRM outcomes of the eight grazing systems under historical weather conditions are shown in Table A6.3. Each of the representative grazing systems is profitable in the long term. Stocking rates are constrained by the requirement to maintain ground cover at 7 of the 8 locations (Moss Vale, the wettest location, being the exception). As expected, profit per hectare is quite closely related to pasture production (Figure A6.2(a)), with the cattle production system at Grenfell being something of an outlier.

Table A6.3. Production and NRM indices for eight NSW grazing systems modelled with the GrassGro decision support tool under historical (1970-1999) climate conditions and an atmospheric CO_2 concentration of 350 ppm. Stocking rates have been adjusted to thee “optimal sustainable” level as defined in the text. A.N.P.P. = aboveground net primary productivity; DSE = dry sheep equivalent.

Location	Enterprise	Mean Annual Rainfall (mm)	A.N.P.P. (t/ha)	Optimal Sustainable Stocking Rate	Clean wool production (kg/ha)	Total live weight sold (kg/ha)
Bungarby	Ewe	550	5.8	2.9	15.8	65
Moss Vale	Cattle	953	11.0	1.56		344
Goulburn	Ewe	674	6.9	5.7	34.2	180
Yass	Ewe	697	9.1	7.0	42.5	222
Woodstock	Ewe	753	8.5	5.9	19.3	360
Young	Ewe	680	8.8	8.1	35.0	190
Culcairn	Ewe	616	8.8	5.2	14.5	443
Grenfell	Cattle	641	6.8	0.62		157

Location	Enterprise	Profit/ha	Frequency (cover<0.7)	Deep Drainage (mm)	Methane per DSE (kg CH_4)
Bungarby	Ewe	85	0.07	30	8.0
Moss Vale	Cattle	301	0.05	171	7.6
Goulburn	Ewe	147	0.07	126	7.2
Yass	Ewe	215	0.07	21	7.2
Woodstock	Ewe	205	0.07	69	7.0
Young	Ewe	198	0.07	82	7.1
Culcairn	Ewe	164	0.07	80	6.7
Grenfell	Cattle	43	0.07	49	7.8

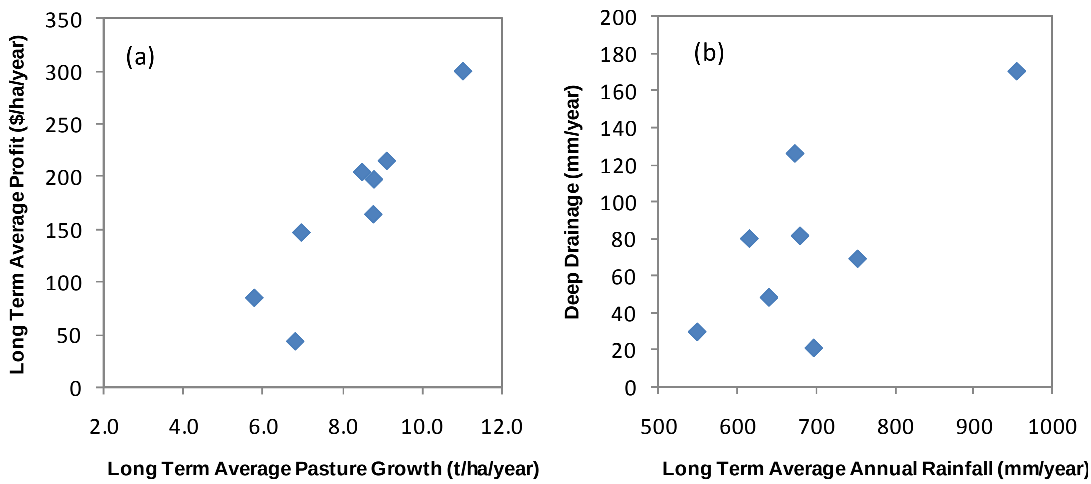

Figure A6.2. Relationships between (a) the long-term average profit and aboveground pasture growth and (b) long-term average deep drainage and rainfall, for eight NSW grazing systems under historical (1970-1999) weather conditions. Values are for the optimal sustainable stocking rate (as defined in the text).

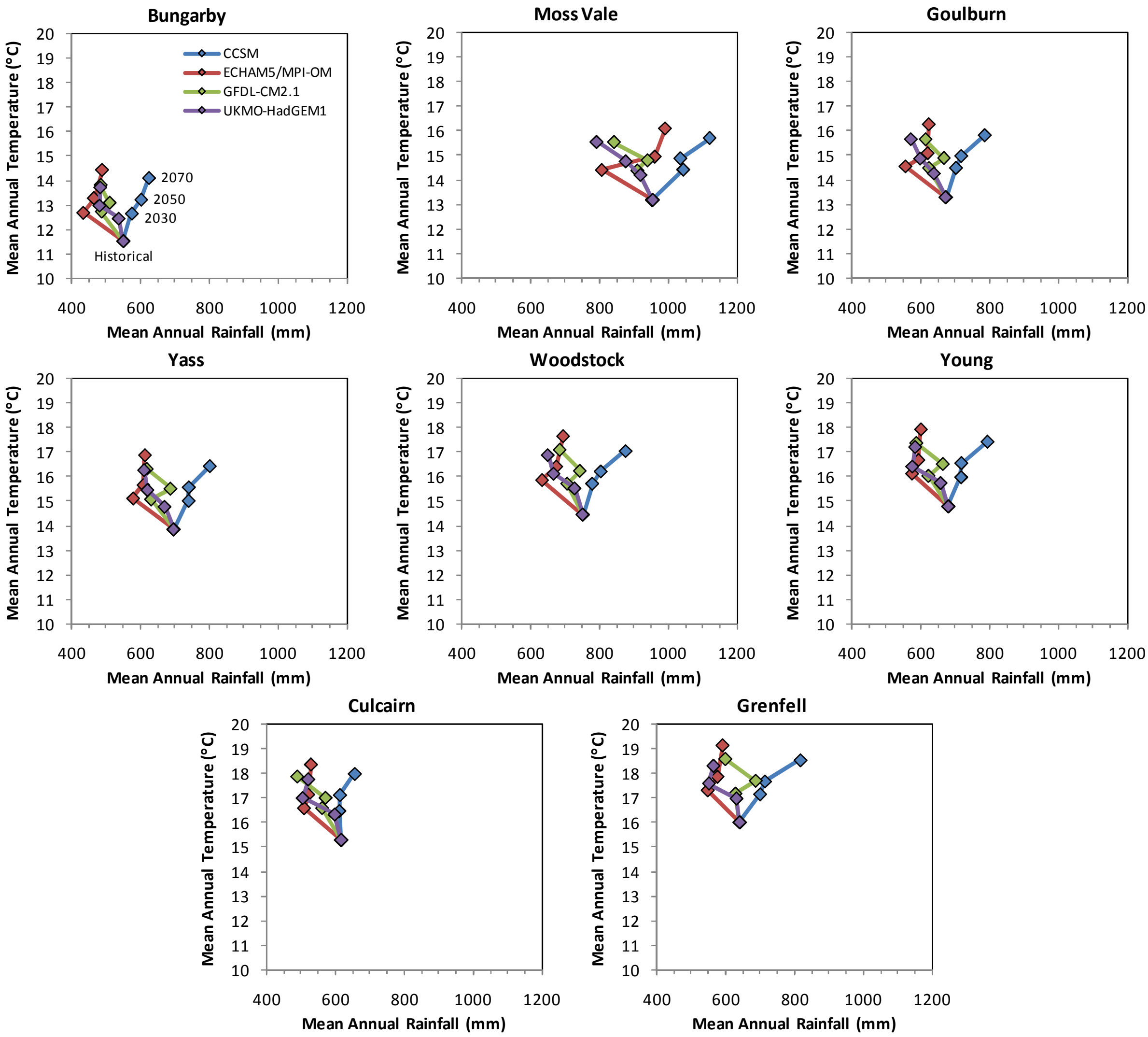

Figure A6.3. Changes in annual rainfall and temperature projected for eight locations in NSW by four global circulation models at 2030, 2050 and 2070. Historical average values (1970-1999) are at the root of each "tree", with the 2030, 2050 and 2070 projections for each GCM shown as a connected line.

There is a relationship between rainfall and deep drainage across sites, but it is not especially strong (R^2 = 0.53) owing to the diverse soil types on which the grazing systems operate. When expressed on a stocking intensity basis, methane production by livestock is quite stable across the eight locations (7-8 kg CH_4/DSE). The lower value at Culcairn is presumably caused by a higher ratio of young stock (which are more energetically efficient) to adult animals.

Climate changes

Figure A6.3 shows the changes in long-term average climate (rainfall and temperature) projected by the four GCMs out to 2070. The projected changes show a high degree of consistency across the eight locations. Under the SRES A2 emissions scenario, the ECHAM5/MPI-OM model predicts a substantial drying to 2030 that is partly recovered in 2050 and 2070 (at Moss Vale, a small increase relative to historic levels is predicted by this GCM at these two dates). CCSM3 predicts a steady increase in rainfall of 6-27% by 2070. The other two GCMs predict a drying trend (with an increase between 2030 and 2050 predicted by GFDL-CM2.1); by 2070 they project similar average annual rainfall to ECHAM5/MPI-OM at most locations.

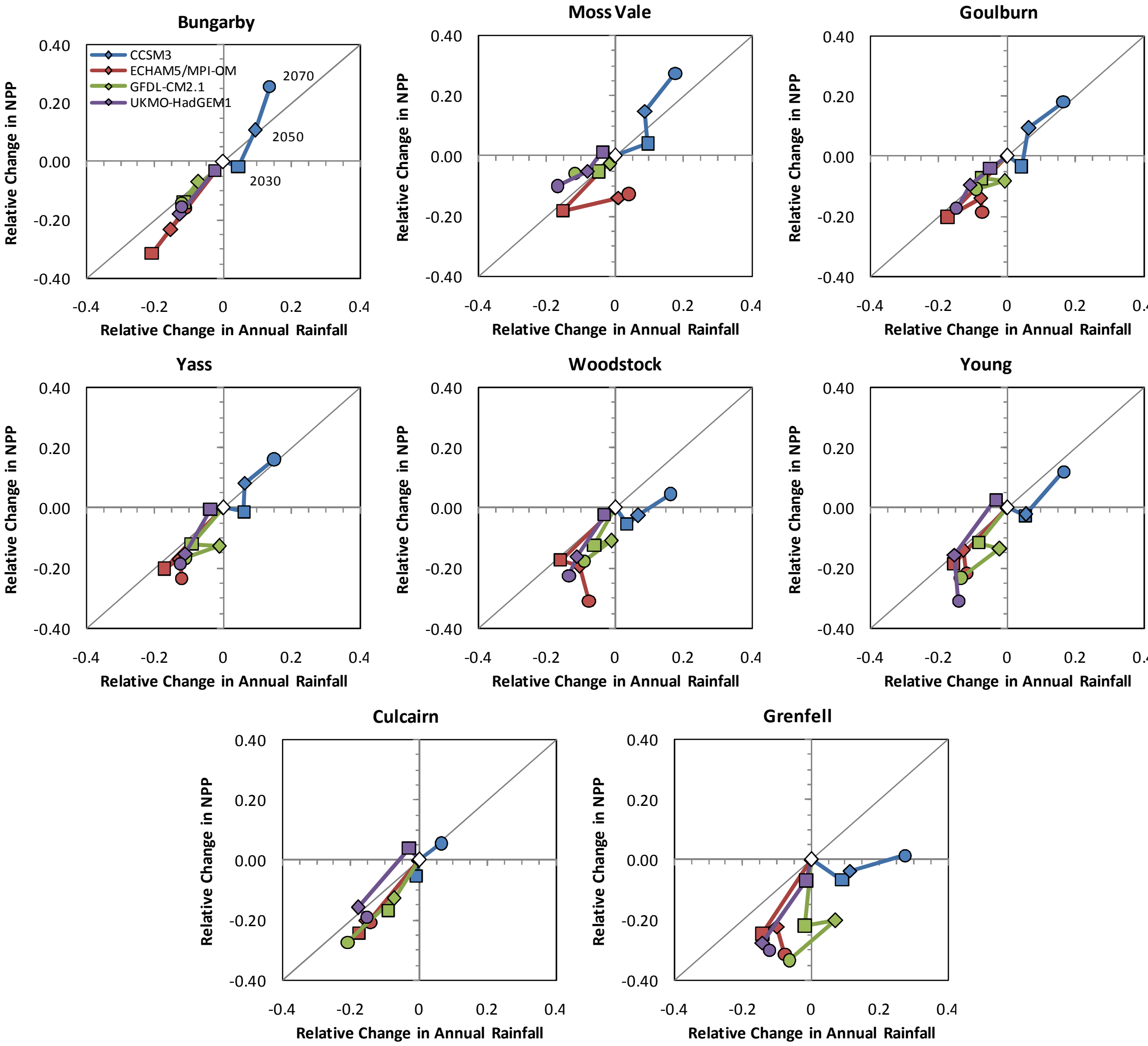

Figure A6.4. Relative change in long-term average aboveground net primary production projected for eight locations in NSW by four global circulation models at 2030, 2050 and 2070, as a function of relative change in long-term average annual rainfall. Historical average values (1970-1999, white diamonds) are at the root of each "tree", with the 2030, 2050 and 2070 projections for each GCM shown as a connected line. The diagonal line indicates equal relative rates of change.

Temperatures are predicted to rise consistently over time across all sites by all GCMs. Projected temperature increases range between 0.9-1.4°C at 2030, 1.5-2.0°C at 2050 and 2.2-3.2°C at 2070; they are largest for ECHAM5/MPI-OM (exacerbating the rainfall decreases predicted by this GCM) and smallest for UKMO-HADGEM1.

Pasture production

As can be seen from Figure A6.4, the projected changes in total rainfall largely determine the changes in pasture growth (aboveground net primary productivity) at all eight locations. At the majority of sites, a given relative change in rainfall is predicted to produce an approximately proportionate change in pasture growth; the main exceptions are the coldest, driest site (Bungarby) and the warmest site (Grenfell). At Bungarby, each 1% change in annual rainfall induces roughly 1.4% change in pasture growth. At Grenfell there is a substantial depression of overall pasture growth rate as temperatures increase (a 6-7% decrease in growth per degree of warming), with the result that relative changes in pasture production are

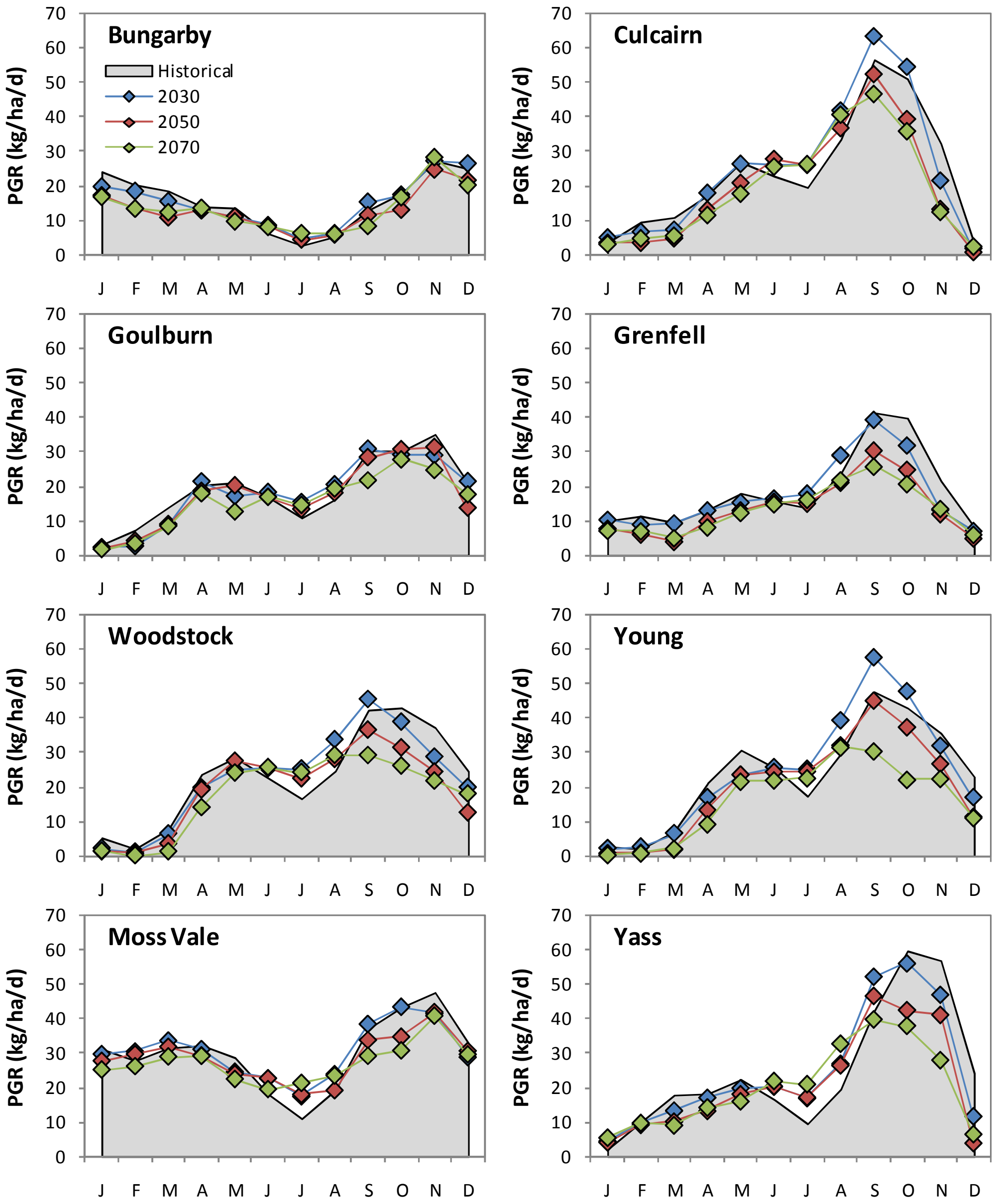

Figure A6.5. Modelled long-term average monthly pasture growth rates (PGR) at eight locations in NSW for climates projected by the UKMO-HADGEM1 model under the SRES A2 emissions scenario. Historical (1970-1999) growth rates for each month are shown as grey shaded areas for comparison.

displaced below the 1:1 line in Figure A6.4. There is some indication that a similar effect operates at the two other sites in the South-west Slopes (Woodstock and Young).

Figure A6.5 shows the projected long-term average patterns of monthly pasture growth rate for one global circulation model (UKMO-HADGEM1). Under this drying projected climate, there is a progressive reduction in the peak growth rate in spring, a shortening of the growing season and an increase in winter growth rates at most locations. At Grenfell, winter growth rates do not increase over time, which explains the decreases in total pasture growth there with increasing temperatures. At Young and Culcairn, growth rates in September-October increase at 2030 and then decrease at 2050 and 2070. The shifts in the projected pattern of pasture growth at Bungarby are distinct from the other 7 locations, with the largest reductions in growth occurring in summer and early autumn.

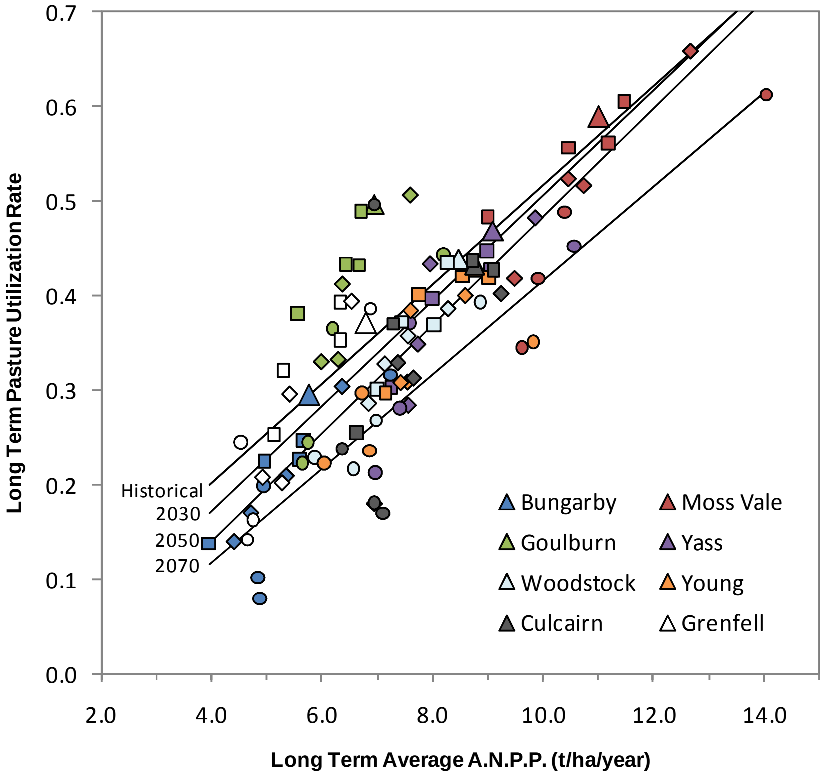

Figure A6.6. Relationships between long-term average pasture utilization rate and aboveground net primary productivity at eight locations in NSW (shown in different colours) for climates projected by four global circulation models under the SRES A2 emissions scenario. △ Historical climate; ☐ 2030 climates; ◇ 2050 climates; ○ 2070 climates. Regression lines for historical climate and for the three future years (with values for Goulburn excluded) are shown as black lines.

Pasture utilization

When the modelling results are compared at the sustainable optimum stocking rate, there is a strong positive relationship between the rate of pasture utilization (pasture consumed:pasture grown) and long-term average pasture ANPP (Figure A6.6) that is reasonably consistent across most of the locations and the 13 climates. The modelled results at Goulburn show a different relationship, however, with a much higher sustainable utilization rate relative to the level of ANPP under historical and 2030 climate. Especially at 2070, there is a tendency for the sustainable utilization rate to fall at a given level of ANPP (Figure A6.6).

Stocking rates and livestock productivity

Table A6.4 shows how changes in pasture growth translate into stocking rates, income from pasture production and finally profit, as averages across the eight sites. The direction of these changes is largely determined by the direction of change in rainfall: for projections derived from the CCSM3 global circulation model rainfall tends to increase and so stocking rate, gross income and profit all tend to rise (at least in 2050 in 2070). For the other three general circulation models, however, rainfall declines in all three future years translate into corresponding or somewhat larger declines in pasture growth. Stocking rates decline by a larger relative amount, since (as shown in Figure A6.6) the sustainable optimum stocking rate generally declines with decreasing pasture production. Income per DSE remains fairly stable, so that changes in gross income are similar in all cases to changes in stocking rate. Finally, owing to the effect of fixed and overhead costs, profit declines faster in relative terms than income

Table A6.4. Relative changes in key production parameters from historical conditions (1970-1999) to 2030, 2050 and 2070, averaged over eight locations in NSW

			Global Circulation Model		
Year	Change in:	CCSM3	ECHAM5/ MPI-OM	GFDL-CM2.1	UKMO-HadGEM1
2030	Rainfall (mm)	+0.05	-0.17	-0.07	-0.03
	Pasture growth (kg/ha/year)	-0.03	-0.22	-0.13	-0.01
	Stocking rate (DSE/ha)	-0.06	-0.47	-0.24	-0.08
	Gross income ($/ha)	-0.06	-0.46	-0.23	-0.07
	Profit ($/ha)	-0.16	-0.86	-0.49	-0.17
2050	Rainfall (mm)	+0.07	-0.10	-0.02	-0.13
	Pasture growth (kg/ha/year)	+0.04	-0.18	-0.11	-0.15
	Stocking rate (DSE/ha)	+0.06	-0.49	-0.27	-0.39
	Gross income ($/ha)	+0.07	-0.48	-0.25	-0.38
	Profit ($/ha)	+0.04	-0.93	-0.48	-0.79
2070	Rainfall (mm)	+0.16	-0.08	-0.12	-0.14
	Pasture growth (kg/ha/year)	+0.14	-0.22	-0.19	-0.21
	Stocking rate (DSE/ha)	+0.10	-0.63	-0.42	-0.60
	Gross income ($/ha)	+0.12	-0.62	-0.41	-0.59
	Profit ($/ha)	+0.11	-1.18	-0.84	-1.12

For two of the general circulation models (ECHAM5/ MPI-OM and UKMO-HadGEM1), the projected climates would result in widespread financial unviability of livestock production in the absence of further adaptation or price changes.

Deep drainage and methane emissions

The levels of deep drainage vary widely from location to location (Table A6.3). As with pasture growth, the projected changes in deep drainage are primarily driven by changes in rainfall; the size of the response differs sharply from location to location, depending on rainfall patterns and the water-holding capacity of the soil. The other two main changes that are expected to affect the water balance are higher evaporative demand due to higher temperatures and reductions in transpiration due to closure of stomata in the presence of higher atmospheric CO_2. These opposite effects produce inconsistent variation around the main rainfall response, depending on the GCM projection and the year (Figure A6.7).

None of the projected climate changes alter the overall quality of pasture consumed enough to shift the expected production of methane per DSE; as a result the projected changes in livestock methane emissions per hectare are almost entirely driven by the changes in the sustainable optimum stocking rate (Figure A6.8).

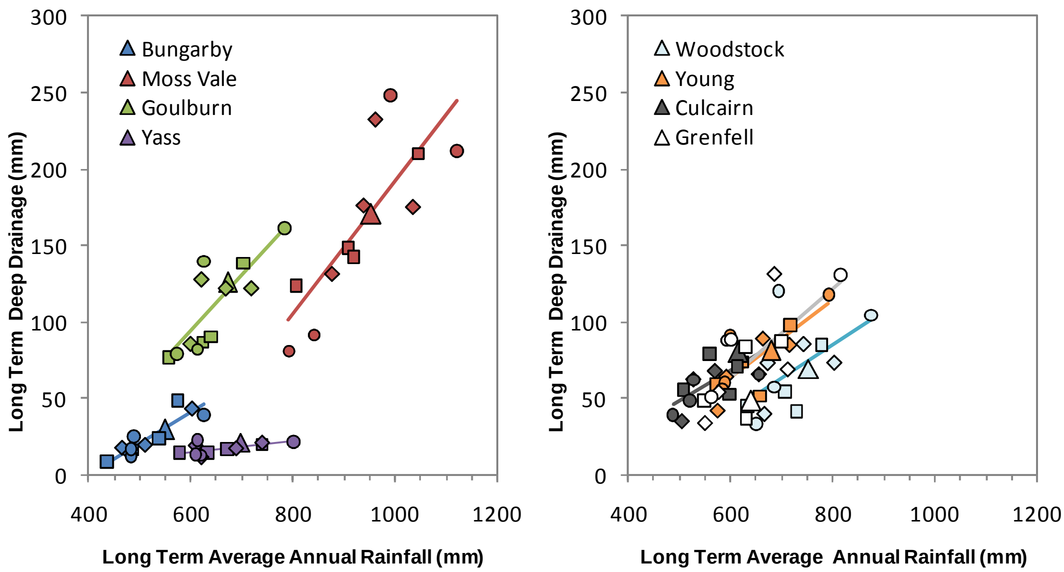

Figure A6.7. Relationships between long-term average deep drainage and rainfall eight locations in NSW (shown in different colours) for climates projected by four global circulation models under the SRES A2 emissions scenario. △ Historical climate; □ 2030 climates; ◇ 2050 climates; ○ 2070 climates. Regression lines each location (across historical and projected climates) are shown as coloured lines.

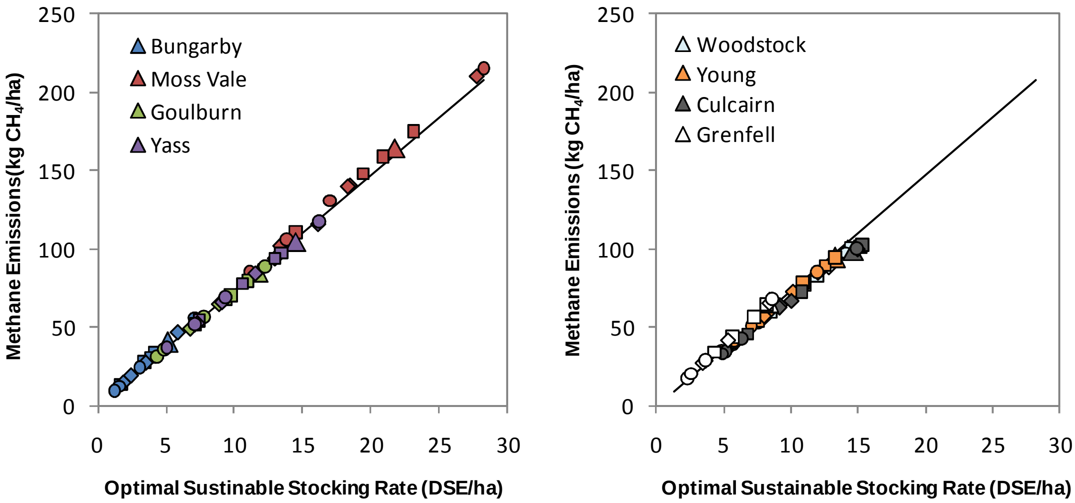

Figure A6.8. Relationships between long-term average methane emissions (on an area basis) and the optimal sustainable stocking rate, expressed as dry sheep equivalents per hectare, at eight locations in NSW (shown in different colours) for climates projected by four global circulation models under the SRES A2 emissions scenario. △ Historical climate; □ 2030 climates; ◇ 2050 climates; ○ 2070 climates. A common regression across all location and climates is shown as a black line.

Discussion

This modelling study has shown that, without doubt, rainfall outcomes will dominate the impacts of a changing climate on the functioning of livestock production systems in southern NSW. Other, more certain impacts (increasing CO_2 concentrations and temperatures) will have secondary effects. It is to be hoped, therefore, that the new round of GCM projections being prepared for the next Assessment Report of the IPCC will deliver smaller levels of uncertainty in their predictions of future rainfall in Australia's agricultural areas.

Across southern NSW, there was a general similarity in the impacts of climate change of the pasture-livestock systems. For three of the GCMs, profits are predicted to decrease sharply over the next six decades owing to decreasing rainfalls producing a disproportionate reduction in sustainable stocking rates (in the absence of other adaptations). Under the climate changes projected by the CCSM3 model, profitability decreases at the majority of sites in 2030 due to less efficient use of rainfall for pasture growth, but at 2050 and 2070 rainfall is projected to increase and this brings stocking rates and profitability back up. Within this general picture, however, each location exhibited individual features, for example the lack of an increase in winter growth rates at Grenfell (Figure A6.5), the shift in month-to-month patterns of pasture growth at Bungarby that was different to all other sites (Figure A6.5) or the insensitivity of deep drainage rates to changes in Rainfall at Yass (Figure A6.7).

Where they can be compared, the results of this study are broadly similar to the results reported for pasture growth changes by Cullen *et al.* (2009), who used different climate projections, a different downscaling technique and a different pasture growth model. For example Cullen *et al.* (2009) report a 5% increase in annual ANPP for Wagga Wagga at 2030 based on a 0.7°C temperature increase and an 8% rainfall decrease; this can be compared to a 4% increase found here for Culcairn (also in the Riverina) using projections for 2030 from GFDL-CM2.1, which imply 1.0°C temperature increase and a 3% rainfall decrease.

It is important to understand that this analysis is an impacts study only. A range of different adaptation options may ameliorate these climate change impacts. It appears, however, that the balance of risk is on the downside and that such adaptive management changes (or ways of increasing product prices relative to input costs) will need to be found and put into practice by livestock producers across southern NSW.

Livestock methane emissions per DSE were very stable across the range of climates & pasture types in southern NSW considered here. We can expect methane emission outcomes under a changing climate to be driven by stocking rate changes, and to a lesser extent by adaptive shifts in flock or herd structures.

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Model results from the UKMO-HADGEM1 model are Crown Copyright 2005, data provided by the Met Office Hadley Centre. We also record our appreciation to the teams responsible for the other three GCMs for making their modelling results available for our research.

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