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Incorporating changes in daily rainfall characteristics into future climate scenarios

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Abstract: Climate change impact modelling, based on future climate scenarios created by direct scaling of historical data, fails to account for projected changes in climate variability. In south-eastern Australia climate change projections for warming and reduced rainfall also suggest changes in daily rainfall characteristics, with more dry days (days with precipitation <1 mm) and increased precipitation intensity on wet days (mm/wet day). This study describes a method for incorporating altered daily rainfall characteristics into future climate scenarios and examines the impact of these scenarios on the production and water balance of two pasture systems in the high rainfall zone of southeastern Australia.

Using Terang (SW Victoria) and Elliott (NW Tasmania) as case studies, historical climate data (1971-2000) was directly scaled according to monthly climate change projections for 2030 and 2070 based on the IPCC A1FI scenario, using output from the CSIRO Mark 3 global climate model. In the 2030 climate scenario, the annual temperature increased by 0.8°C and 0.7°C at Terang and Elliott, with 8% and 6% annual rainfall declines at the respective sites. In the 2070 scenario, temperatures at Terang and Elliott were increased by 2.8°C and 2.5°C, with rainfall reduced by 29% and 20% respectively. At both sites, most of the rainfall reduction was projected to occur in spring. To test the sensitivity of the production and water balance of pasture systems to altered number of dry days and precipitation intensity, two treatments with altered daily rainfall characteristics were created for both the 2030 and 2070 future climate scenarios, whereby rainfall events greater than the average event in each scenario were increased by either 10% or 20%, with events less than the average decreased to keep the long-term average annual rainfall the same. The directly scaled future rainfall scenarios had slightly more dry days than the historical climate but had lower precipitation intensity, while the altered daily rainfall 10% and 20% treatments had progressively more dry days with higher precipitation intensity than the historical scenario. It was concluded that projected changes in daily rainfall characteristics were effectively captured in these treatments.

The effects of climate scenarios on pasture production and water balance were simulated using the biophysical model DairyMod. Simulated annual mean dryland pasture production at Terang increased by 4% in the 2030 scaled future climate scenario and decreased by 19% in the 2070 scaled scenario, while at Elliott mean irrigated pasture production increased by 11% and 10% in the 2030 and 2070 directly scaled scenarios compared to the historical baseline. The altered daily rainfall treatments had little additional impact on the productivity of dryland pastures at Terang or irrigated pasture at Elliott beyond the changes observed in the direct scaling scenarios. However the altered daily rainfall treatments did impact on the water balance at both sites. At Terang, the direct scaling rainfall treatment reduced the amount of runoff simulated, but the altered daily rainfall treatments increased runoff. At Elliott, the drier climate change scenarios all indicated an increase in the irrigation water required, but the requirements were higher in the altered daily rainfall treatments compared to direct scaled. This indicates that current irrigation practices will not be efficient in a future climate where rainfall occurs on fewer days with higher intensity, and irrigation strategies that maximize the use of rainfall will be increasingly important.

Considerable uncertainties exist about climate change projections and mean climate changes are currently better described than changes in rainfall variability or daily rainfall characteristics. However, these results indicate that while direct scaling of climate data, that incorporate mean climate changes, may be adequate to assess the impacts on annual pasture production, altered daily rainfall characteristics are important to assess impacts on net water balance.

Keywords: *climate change, grazing systems, DairyMod*

1. INTRODUCTION

Future climate scenarios for climate change impacts assessment on biological systems are constructed using historical climate data and projections for future temperature, rainfall and other climatic variables together with predicted atmospheric carbon dioxide (CO_2) concentrations. These are key climate inputs for agricultural systems models that are used to assess climate impacts on production systems, for example on wheat yield or pasture supply. Climate change projections for temperature and rainfall are currently available from a number of global climate models via tools such as CSIRO's OzClim database (www.csiro.au/ozclim). These projections are for changes in mean temperature and rainfall and are available on annual, seasonal or monthly time-steps and as such they can be effectively used to construct future climate scenarios that reflect change in both total annual rainfall and the seasonal distribution of rainfall. While this approach captures the average changes in climate, and has been widely used in climate change impact analysis in agricultural systems (van Ittersum et al., 2003; Anwar et al., 2007; Cullen et al., 2009), the future climate scenarios generated reflect historic variability and do not take into account projected changes in temperature and rainfall variability. In south eastern Australia, climate change projections are for reduced rainfall but also for changes in daily rainfall characteristics with an increase in the number of 'dry' days (days with rainfall less than 1 mm) and an increase in rainfall intensity (mm/wet day) on 'wet' days (CSIRO and BoM, 2007; Alexander and Arblaster, 2009). Thus, incorporating increases in precipitation intensity and the number of dry days should lead to improved representation of future climate scenarios (Kilsby et al., 2007).

The aims of this paper were to demonstrate a method for manipulating historical rainfall to better reflect the projected changes in daily rainfall characteristics, and using a sensitivity analysis approach, to determine the impact of these changes on production and water balance in grazing systems using the biophysical model DairyMod (Johnson et al., 2003; 2008).

2. MATERIALS AND METHODS

2.1. Climate data and future climate scenarios

The future climate scenarios were created for two sites in the high rainfall dairy regions of southeastern Australia - Terang in the temperate region of southwest Victoria and Elliott in the cool temperate zone of northwest Tasmania. Daily climate data for both sites for the period 1/1/1971 to 31/12/2000 were obtained from the SILO database (http:// www.longpaddock.qld.gov.au/silo/, Jeffery et al., 2001), which is maintained by the Queensland Environmental Protection Agency and is based on data from the Australian Bureau of Meteorology. Terang is warmer than Elliott (Figure 1) and both sites have a winter-dominant rainfall (Figure 1), although mean annual rainfall for the period 1971-2000 at Elliott (1220 mm) is considerably higher than at Terang (746 mm, Figure 2).

Future climate scenarios representing 2030 and 2070 climates were created for both sites, based on the historical 1971-2000 climate. Monthly temperature (°C) and rainfall (%) change projections from the CSIRO Mark 3 climate model were obtained from the OzClim database (www.csiro.au/ozclim) using the A1FI emission scenario (IPCC 2000) in 2030 and 2070, and output from the CSIRO Mark 3 global climate model. At Terang in the 2030 climate scenario, the annual temperature increased by 0.8°C and rainfall declined by 8%, while in the 2070 scenario the temperature increase was 2.8°C and rainfall decline 29%. At Elliott in the 2030 climate scenario, annual temperature increased by 0.7°C and rainfall declined by 6%, while in the 2070 climate scenario the temperature increase was 2.5°C and rainfall decline 20%. At both sites, most of the projected rainfall reduction was predicted to occur in spring. Mean monthly rainfall, minimum and maximum temperature for the historical and the 2030 and 2070 scaled future climate scenarios are shown in Figure 1.

For both 2030 and 2070, three future climate scenarios were created by handling rainfall in different ways. In the first method, future daily rainfall was determined by direct scaling of daily historical climate data according to the change scenario, i.e. all daily rainfall values were changed by the monthly mean projections. For example rainfall on 4th January 1991 at Elliott was 6.6 mm and climate change projections for 2030 and 2070 indicated 7.9 and 28.6% rainfall reductions in January, so rainfall on this day in the 2030 and 2070 future scenarios was scaled to 6.1 and 4.7 mm respectively. In this paper, this rainfall treatment is referred to as the 'scaled' rainfall treatment.

In the other two rainfall scenarios, changes in daily rainfall characteristics were accounted for, using the following terms defined by CSIRO and BoM (2007) as:

- Precipitation intensity – the annual precipitation (mm) divided by the number of wet days (ie. days with > 1 mm precipitation).
- Number of dry days – annual days with <1 mm precipitation.

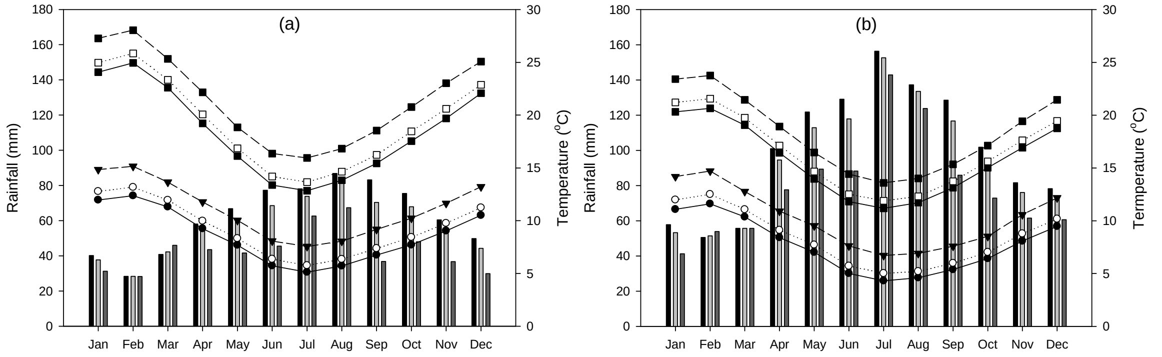

Figure 1. Mean monthly climate statistics for (a) Terang and (b) Elliott, showing rainfall (mm) for baseline (■) 2030 scaled (░) and 2070 scaled (▓) scenarios, minimum temperature (°C) for baseline (—●—), 2030 scaled (⋯○⋯) and 2070 scaled (– ▼ –) scenarios, and maximum temperature (°C) for baseline (—■—), 2030 scaled (⋯□⋯) and 2070 scaled (– ■ –) scenarios.

To simulate the increases in precipitation intensity and the number of dry days expected in southeastern Australia, two altered daily rainfall scenarios were created whereby rainfall events greater than the average event were scaled to increase by 10 and 20%, with reductions to rainfall events less than the average made to keep the long-term average annual rainfall the same. The decision to scale events above and below the average, and to increase events greater than average by 10 and 20% were subjective but designed to capture the broad changes in daily rainfall characteristics projected (CSIRO and BoM, 2007; Alexander and Arblaster, 2009) and create a range of rainfall scenarios for the sensitivity analysis. In practice, the altered daily rainfall scenarios were implemented as follows. In the Terang 'baseline' climate data the average rainfall event was 3.5 mm. To create the altered daily rainfall 10 and 20% treatments, rain events greater than 3.5 mm were increased by 10% and 20%, with reductions of 33 and 66% for below average rainfall events imposed to keep the long-term average annual rainfall the same. At Elliott the average rainfall event was 6.0 mm in the 'baseline' climate data. To create the altered daily rainfall 10 and 20% treatments, rain events greater than 6.0 mm were increased by 10% and 20%, with reductions of 45 and 85% for below average rainfall events imposed to keep the long-term average annual rainfall the same.

Hereafter, these rainfall scenarios will be referred to as the 'Altered Daily Rainfall (ADR) 10%' and 'ADR 20%' treatments.

2.2. Sites and pasture systems simulated

The future climate scenarios were used to model pasture production systems at Terang (SW Victoria) and Elliott (NW Tasmania). The location and soil types of both sites are described in Table 1, with historical annual rainfall distribution in Figure 2. The brown chromosol at Terang had a high plant available water-holding capacity (PAWC) and is subject to periodic water-logging in winter, while the red ferrosol at Elliott had a low PAWC and was free draining. Perennial ryegrass (*Lolium perenne*)/ white clover (*Trifolium repens*) was the pasture at both sites and a simple 'put and take' grazing system was used for all scenarios whereby animal numbers were adjusted daily to maintain pasture mass at 2 tonnes (t) DM/ha and removed when it was less than this value so as not to bias production by applying inappropriate grazing management. Dryland pasture production was simulated at Terang, while an irrigated system was simulated at Elliott with irrigation applied regularly to keep the soil profile close to field capacity.

Simulations were carried out using the biophysical model DairyMod (Johnson et al., 2003; 2008), which has been shown to adequately simulate pasture systems in the high rainfall pasture systems of Australia and New Zealand (Cullen et al., 2008; White et al., 2008). Effects of elevated CO_2 concentrations (455 ppm in 2030 and 716 ppm in 2070) on increasing solar radiation and water use efficiencies on plant growth (Cullen et al., 2009) were included in these simulations.

Table 1. Description of the Terang and Elliott sites, including location, soil type (Isbell 1996) and PAWC (mm, 0-40cm).

Site	Lat. Long.	Soil type	PAWC (mm)
Terang	-38.15, 142.55	Brown chromosol	81
Elliott	-41.08, 145.77	Red mesotrophic haplic ferrosol	36

2.3. Data analyses

Rainfall data at the two sites were described using annual mean, number of dry days and precipitation intensity. No formal statistical analysis was applied to the modelled pasture growth and water balance outputs because of inter-correlations in the input climate data and the mechanistic, non-stochastic nature of the model used. Trends are presented across the range of future climate scenarios, with the inter-annual variability presented where appropriate. Modelling outputs were summarized on an annual basis over the 30 year simulation runs for each climate scenario. The model metrics were pasture production (t DM/ha), drainage through the soil profile (mm), runoff (mm) and irrigation applied (mm).

3. RESULTS

The annual rainfall and daily rainfall characteristics for each of the climate scenarios are reported in Table 2 for both sites. The scaled rainfall treatments reduced the annual rainfall, but had a relatively small impact on the number of dry days and reduced the precipitation intensity. The ADR 10% and 20% treatments had very similar mean annual rainfall, but an increased number of dry days and higher precipitation intensity compared to the scaled treatment (Table 2). There was an increase in the variability of annual rainfall in the ADR treatments (Figure 2).

Table 2. Mean annual rainfall (mm), number of dry days and precipitation intensity (mm/day) for the baseline, and 2030 and 2070 climate scenarios with scaled and ADR 10% and 20% treatments at Terang and Elliott.

			2030			2070	
	Baseline	Scaled	ADR 10%	ADR 20%	Scaled	ADR 10%	ADR 20%
			Terang				
Annual Rainfall	746	683	684	688	518	518	519
Dry days	230	237	258	297	251	274	301
Precip. intensity	5.7	5.3	6.4	10.0	4.5	5.7	8.0
			Elliott				
Annual Rainfall	1220	1151	1146	1152	970	965	970
Dry days	231	236	256	303	242	263	304
Precip. intensity	9.5	8.9	10.5	18.6	7.9	9.5	15.8

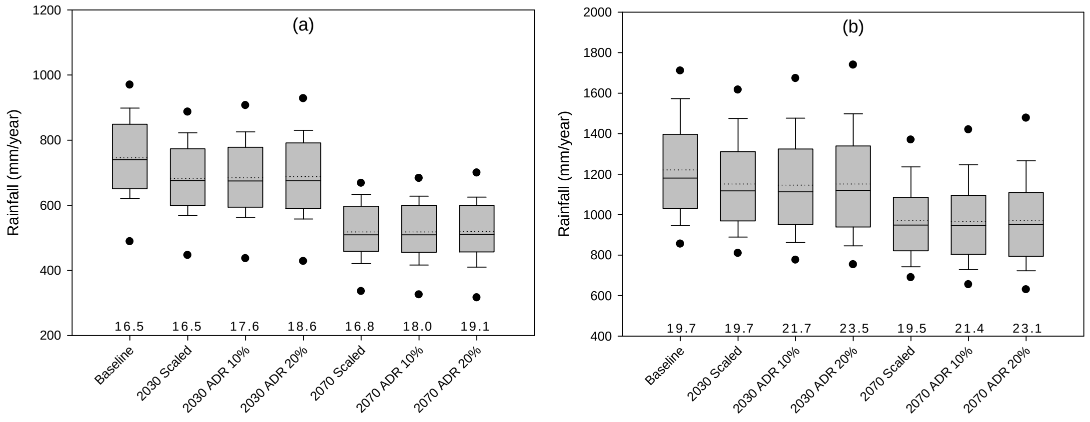

Figure 2. Annual rainfall (mm) at (a) Terang and (b) Elliott for the baseline, and 2030 and 2070 climate scenarios with scaled and ADR 10% and 20% rainfall treatments. Box-plots show the distribution of outputs over 30 years (5th, 10th, 25th, 50th, 75th, 90th and 95th percentiles shown, with mean indicated by dotted line). Inter-annual variation in annual rainfall (CV%) is shown on the bottom line.

Annual pasture production increased by 4% in the 2030 scaled scenario compared to the baseline at Terang but was reduced 19% in the 2070 scaled scenario (Figure 3). The increase in 2030 was due to warmer temperatures and increased efficiencies from higher atmospheric CO_2 concentrations (Cullen et al., 2009), while the reductions in 2070 were caused by higher temperatures and reduced spring rainfall. At Elliott, irrigated pasture production was higher than the historical baseline in both the 2030 and 2070 scaled future climate scenarios, but variability was higher in 2070 (Figure 3). At both sites, there was little difference in the distribution of annual pasture production between the scaled and ADR 10% and 20% treatments in 2030 or 2070 (Figure 3).

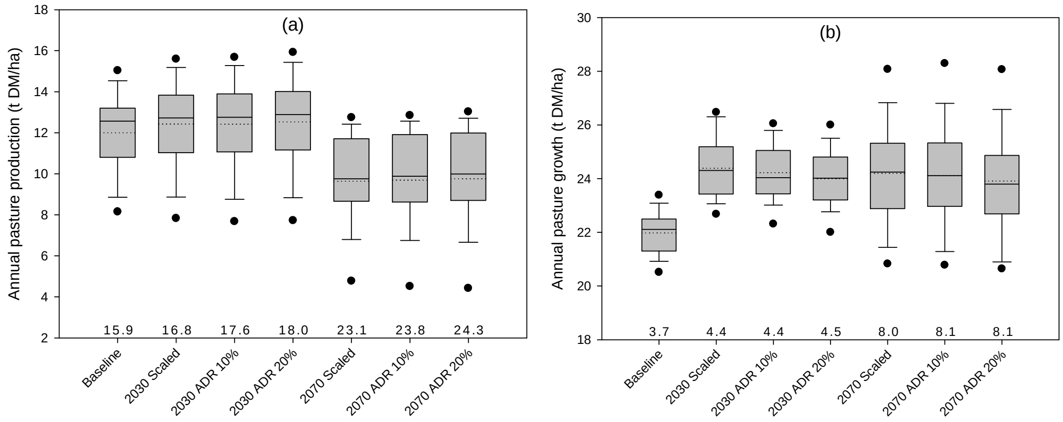

Figure 3. Annual pasture production (t DM/ha) at (a) Terang and (b) Elliott for the historical baseline, and 2030 and 2070 climate scenarios with scaled and ADR 10% and 20% rainfall treatments. Box-plots show the distribution of outputs over 30 years (5th, 10th, 25th, 50th, 75th, 90th and 95th percentiles shown, with mean indicated by dotted line).

Water balance (runoff, irrigation and drainage) are shown where appropriate for Terang and Elliott in Figures 4 and 5. At Terang, under the scaled treatment in 2030 and 2070 there was a reduction in the amount of runoff and drainage compared to the baseline (Figure 4) in line with the reduced average rainfall (Figure 2). However, in the ADR treatments runoff was increased above the scaled treatment in both 2030 and 2070, with little change in drainage (Figure 4).

In the irrigated pasture system at Elliott, there was a marked effect of the ADR treatments increasing irrigation requirements over and above the effects of the scaled rainfall treatments (Figure 5). No run off was noted due to the high permeability of the soil type. Increased irrigation inputs were carried through to increased deep drainage (Figure 5).

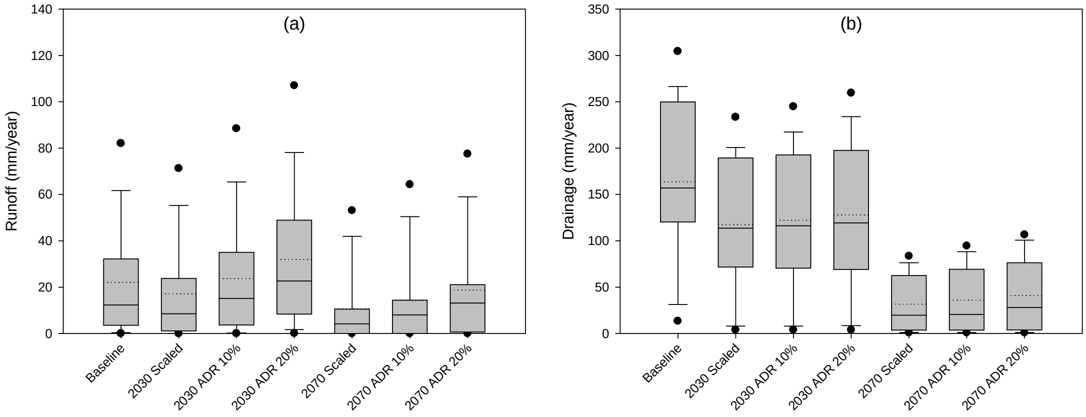

Figure 4. Annual water balance at Terang showing (a) surface runoff (mm) and (b) drainage (mm) for the historical baseline, and 2030 and 2070 climate scenarios with scaled and ADR 10% and 20% rainfall treatments. Box-plots show the distribution of outputs over 30 years (5th, 10th, 25th, 50th, 75th, 90th and 95th percentiles shown, with mean indicated by dotted line).

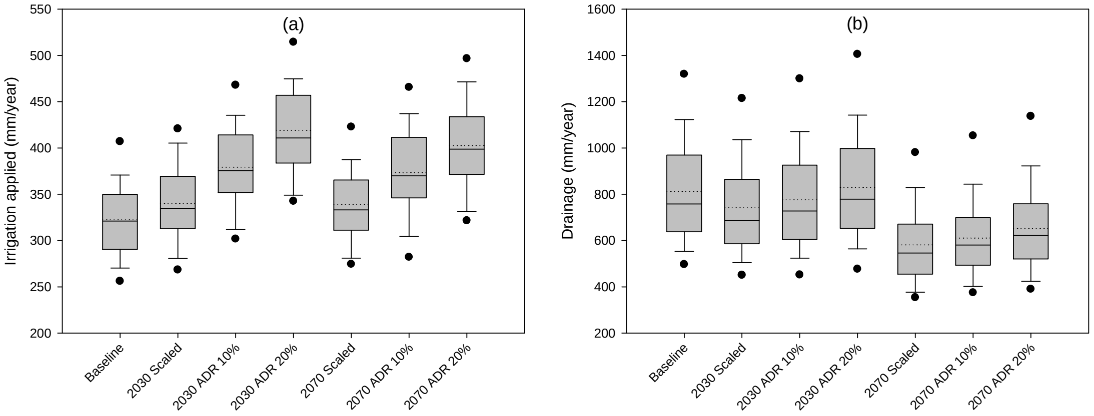

Figure 5. Annual water balance at Elliott showing (a) irrigation applied (mm) and (b) drainage (mm) for the historical baseline, and 2030 and 2070 climate scenarios with scaled and ADR 10% and 20% rainfall treatments. Results are presented as box-plots showing the distribution of outputs over 30 years (5th, 10th, 25th, 50th, 75th, 90th and 95th percentiles shown, with mean indicated by dotted line).

4. DISCUSSION AND CONCLUSIONS

The method used to alter daily rainfall characteristics, by increasing the volume of rainfall events greater than the historical average event and reducing the volume of events less than average, was shown to be an effective means to generate rainfall scenarios that capture both changes in mean rainfall as well as changes increases in precipitation intensity and the number dry days (Table 1). The ADR 10% treatment produced 0-1 mm/day increases in precipitation intensity compared to the baseline climate, in line with projections for increased precipitation intensity to 2100 (CSIRO and BoM, 2007; Alexander and Arblaster, 2009), however the 2-9 mm/day increases generated in the ADR 20% treatment are higher those projected. These treatments also produced rainfall scenarios with greater variability in annual rainfall. The simple methodology allowed a range of rainfall treatments to be investigated. Other approaches to changing daily rainfall characteristics, such as scaling each event based on its decile of daily rainfall, could also be used to generate rainfall scenarios for climate change risk assessment.

In this study, pasture production at Terang was increased in 2030, due to warmer temperatures and increased efficiencies from higher atmospheric CO_2 concentrations (Cullen et al., 2009), but reduced in 2070 due to higher temperatures and reduced spring rainfall (Figure 3). At Elliott, irrigated pasture production was higher than the baseline in 2030, and similar to 2030 but with more variability in 2070 as high temperature stresses began to limit plant production (Figure 3). These effects were captured by both the scaled and altered daily rainfall scenarios. The finding that the ADR treatments had little additional impact on annual pasture production in the high-rainfall dairy regions of southeastern Australia indicates that directly scaled future rainfall scenarios may be adequate for the analysis of climate change impact on plant production in these regions. This confirms the applicability of studies that have used this scaling approach to investigate climate change impacts on wheat yield (eg. van Ittersum et al., 2003; Anwar et al., 2007) and pasture production (Cullen et al., 2009).

The differences between the scaled and altered daily rainfall characteristics scenarios were more evident in the modelled water balance responses. At Terang, the altered rainfall characteristics produced more runoff (Figure 4), associated with higher precipitation intensity (Table 2). At Elliott, more irrigation water was required (Figure 5). This finding brings into question the current irrigation practices that maintain soil moisture levels near field capacity. Under these conditions higher precipitation intensity leads to more drainage following rainfall events resulting in poorer rainfall use efficiency. These results indicate that deficit irrigation strategies (eg. Rawnsley et al., 2009) will be increasingly appropriate under future climate scenarios, particularly when changes to the daily rainfall characteristics are considered.

While considerable uncertainties exist about climate change projections, information about regional changes in mean climate is more readily available than changes in climatic variability. This reflects limited availability of monthly and daily rainfall data from climate models, and limited resources for generating climate projections. Similar to rainfall, climate change projections for daily temperature also suggest a change from the historical pattern of variability, with a higher frequency of hot days and heat waves in southern Australia (Alexander and Arblaster, 2009). Changes in the frequency and/or timing of hot (or cold) stresses are likely to have important implications for plant-based production systems, for example by causing plant mortality and leading to a need to re-sow pastures. Approaches like those adopted here to alter daily rainfall characteristics in line with climate change projections should also be considered for future temperature scenarios. The results presented in this paper indicate that while direct scaling approaches that incorporate mean rainfall changes into future climate scenarios may be adequate to assess the impacts on annual pasture production, altered daily rainfall characteristics must be considered when assessing impacts on net water balance.

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