Climate change impacts in the Hunter Valley

A risk assessment of heat stress affecting dairy cattle

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CSIRO Atmospheric Research

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Summary

This report provides a real world application of a risk assessment framework for climate change developed by CSIRO. The framework is applied to thresholds of heat stress in dairy cattle under climate change in order to estimate the risk of losses to milk production. Options for adaptation to reduce risk are also analysed.

This study is based on historical climate and projected climate change for Muswellbrook in the Hunter Valley of New South Wales. Heat stress in cattle is associated with high temperature and humidity. Projected increases in temperature due to climate change will increase heat stress with resultant negative impacts, including reduced milk production. The probabilities of changes in maximum temperature and dewpoint temperature take three types of uncertainty into account:

- future greenhouse gas and sulfate aerosol concentrations
- the sensitivity of climate to these concentrations
- regional patterns of climate change from six different climate models.

A Temperature Humidity Index (THI) applied to dairy cattle in Australia by Davison et al. (1996) was used for the Muswellbrook study. Two critical THI thresholds are considered:

> **72** milk yield starts to decline for cows with no shade
> **78** milk yield starts to decline for cows with shade and a sprinkler system

The probability of heat stress exceeding these THI levels between the years 2010 and 2090 is computed using ranges of change for maximum temperature and humidity. The probability of milk losses at a rate of 0.35 L/cow/THI unit is then estimated.

Under current climate, average milk losses are 232 L/cow/year for cows with no shade (or 3.3% of annual production). By the year 2030, milk loss for cows without shade approaches 280 L/cow/year or 4% of annual production. By 2070, the milk loss is 250 to 400 L/cow/year, or 6% of annual production. Risk profiles show the likelihood of a particular rate of loss from 2010 to 2090.

The benefits of adapting by installing shade and sprinklers are shown. Milk losses under current climate are reduced to 55 L/cow/year (or 0.8% of annual production), a 2.5% improvement on having no shelter. In 2030, adaptation restricts losses to 60 to 70 L/cow/year or 1% of annual production. In 2070, adaptation restricts the milk loss to 65 to 120 L/cow/year and saves from 3 to 4% of annual milk production. Preliminary costing indicates a financial benefit from adaptations to current climate, and shows that those benefits will increase under climate change.

This project illustrates how risk analysis can be used to manage the substantial uncertainties surrounding climate change and how risk assessment produces results in a form suitable for

use in planning and management. Applying this methodology to a catchment-scale integrated assessment of the Hunter Region is proposed.

Introduction

Uncertainty is the most problematic aspect of climate change science, limiting the utility of climate change impact assessments and appropriate policy responses. System uncertainties such as future greenhouse gas emission pathways, regional responses to global warming and the chaotic behaviour of the climate system ensure that straightforward predictions of climate change in the form of $x \pm y$ (a singular outcome with associated confidence limits) cannot be made. At best, given our current knowledge of complex systems, a range of impacts bound by a high and low extreme with a defined probability distribution can be produced (Jones, 2000a). This range can be very large, and creates substantial difficulties for policy and planning.

CSIRO Atmospheric Research has developed a risk assessment framework that aims to reduce these difficulties. Rather than predicting a particular impact from one or more projected climate changes, the analytical phase aims to calculate the risk of exceeding a level of impact with a known outcome (an impact threshold). Where the risk of exceeding a threshold is sufficiently high, adaptation options to reduce that risk may be proposed and assessed. Stakeholders are central to this framework. They are involved in nominating various thresholds for assessment, assessing the risk attached to probabilities of exceedance, and in the framing and assessment of adaptation options. This involvement provides an integrated social and scientific context for adapting to climate change.

The risk assessment framework has been applied as part of a joint project between the NSW Government and CSIRO Atmospheric Research, entitled "Scoping study for integrated assessment of climate change impacts for the Hunter Valley". Under this project, a recommendation was made to trial the framework on thresholds of heat stress in dairy cattle and to report the results to a regional stakeholder workshop. This report describes the method used to analyse the changing risk of milk loss in dairy cattle under climate change. The study is based on models of milk loss under historical climate at Muswellbrook and estimates the probability of milk losses from now until 2090. Adaptations are assessed in relation to current activities, production levels and planning horizons. The approach and conclusions show how risk assessment can be used in long-term planning and management of the uncertainties surrounding climate change. A recommendation for further development of the risk assessment framework for integrated impact assessment in the Hunter Valley concludes the report.

Background

The Hunter Valley was chosen for the scoping study on integrated assessment because of its diverse geography and economic activity, its high level of integration of processes and activities, and the availability of high-resolution regional climate change scenarios from CSIRO. The aim of the study was to determine how climate change science can meet the needs of stakeholders on a regional and integrated basis. The risk assessment framework developed by CSIRO was applied as a major part of the study.

Stakeholder consultation occupied the first half of the project. CSIRO briefed relevant Government Departments and the Hunter River Management Committee, and sought written contributions about climate change issues from key stakeholders. A stakeholder workshop held in Newcastle on 6 May 1999 is reported in Hennessy and Jones (1999). The workshop led to the following conclusions:

- Workshop participants have significant insight into how climate affects many activities in the Hunter Region, how these activities interact with each other, and the planning strategies that might assist adaptation to climate change.
- Water supply was nominated as a key issue. Most of the thresholds related to water are the product of a complex series of relationships in which feedbacks are often present. Consequently they are difficult to model and to characterise in terms of risk.
- Heat stress was also identified as a priority issue. Relevant databases, research and models are available for assessing the impact of climate change on heat stress affecting cattle. It would be possible to perform a simple risk assessment, given certain assumptions about the distribution of daily temperature variability under climate change.

The workshop report recommended that a pilot risk assessment on heat stress affecting dairy cattle be carried out, a proposal that was endorsed by the NSW Climate Adaptation Steering Committee. The risk assessment builds upon the work of Davison et al. (1996) in "Managing hot cows in Australia" and the greenhouse projections of Hennessy et al. (1998) in "Fine resolution climate change scenarios for New South Wales".

CSIRO's risk assessment framework for climate change impacts and adaptation is shown in Figure 1. The framework follows the following steps:

1. Identify the **key climatic variables** affecting the exposure units being assessed.
2. Create **scenarios** and/or projected ranges for key climatic variables.
3. Carry out a **sensitivity analysis** to assess the relationship between climate change and impacts.
4. Identify the impact **thresholds** to be analysed for risk with stakeholders.
5. Carry out **risk analysis**.
6. Evaluate risk and identify feedbacks likely to result in **autonomous adaptations**.
7. Consult with stakeholders, analyse proposed adaptations and recommend **planned adaptation** options.

Through consultation with stakeholders at the workshop on 6 May 1999, we discussed key issues and activities that are sensitive to climate, and identified critical variables and impact thresholds in Davison et al. (1996). The risk analysis and adaptation assessment components are described below.

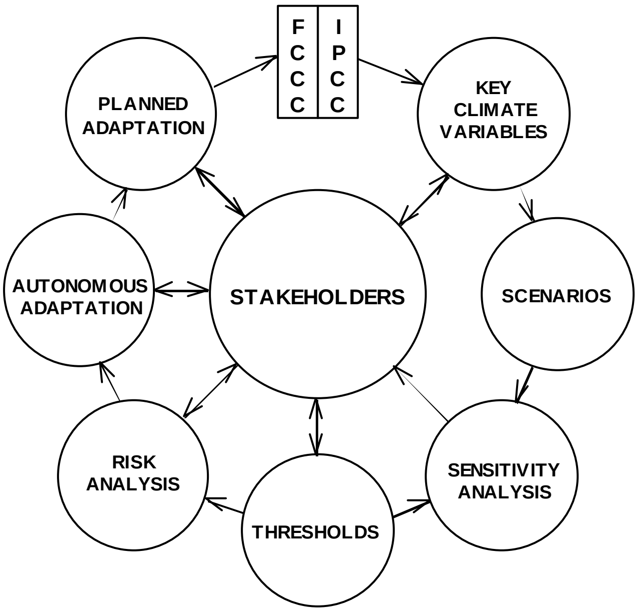


Figure 1. Risk assessment framework for assessing climate change impacts (from Jones, submitted). The Intergovernmental Panel on Climate Change (IPCC) and United Nations Framework Convention on Climate Change (FCCC) form the starting and end points of the process.

Dairy cattle response to heat stress

Dairy farming in the Hunter Valley has a turnover of about $90 million per year (Hennessy and Jones, 1999). Most of the industry is situated on the alluvial soils of the lower reaches of the Hunter River downstream from Muswellbrook. Our study is based on historical climate and the associated levels of heat stress and projected climate change centred on Muswellbrook. Heat stress in dairy cattle is associated with high temperature and humidity. Projected increases in temperature due to climate change would lead to more heat stress and a number of negative impacts, including reduced milk production.

A comprehensive assessment of the response of dairy cattle to heat stress in New South Wales and Queensland has been undertaken by Davison et al. (1996). They measured heat stress using a Temperature Humidity Index (THI) calculated as

$$THI = T_{max} + 0.36\ T_{dewpoint} + 41.2$$

where T_{max} is the daily maximum dry bulb temperature (^{o}C) and $T_{dewpoint}$ is the daily dewpoint temperature (^{o}C). Dewpoint temperature is related to vapour pressure (VP in hectopascals) by the equation

$$T_{dewpoint} = (273.3 \times (VP / 6.107)) / (17.269 - \ln (VP / 6.107))$$

Dewpoint is the temperature at which a cooling "parcel" of air becomes saturated by its water vapour content. It is closely related to both relative humidity and vapour pressure, and conversions between the three variables can be readily carried out. As temperature and/or dewpoint temperature increases, the effectiveness of evaporative cooling declines, discomfort due to heat stress rises and the THI increases.

Davison et al. (1996) summarised dairy cattle responses to heat stress in terms of physiological and production effects, paraphrased below:

Physiological effects

- Cows seek shade (which reduces grazing time, when stress periods are prolonged)
- Reduced food intake
- Weight loss
- Open mouths and laboured breathing
- Decreased reproduction rate
- Increased somatic cell counts and risk of clinical mastitis
- Increased body temperature and respiration rate
- Inability to move
- Collapse, convulsions, coma, death

Production effects

- The cows with highest milk yield are the first to show heat stress symptoms
- Cows with no shade producing above 20 L/day experience stress when THI exceeds a value of 72. Mild stress occurs for a THI of 72 to 78, leading to decreased milk yield, milk fat content and protein content
- For cows with no shade producing above 20 L/day, significant stress occurs for a THI of more than 78, and milk yield declines markedly
- Cows with shade and sprinklers producing above 20 L/day experience stress when the THI exceeds 78 (Figure 2).

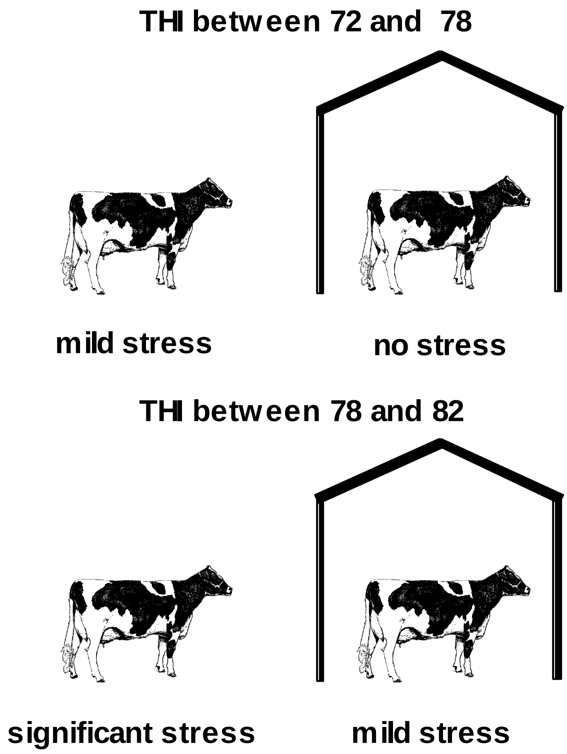


Figure 2: Unshaded cows experience mild stress when the Temperature Humidity Index (THI) is 72-78 and significant stress when the THI exceeds 78. Cows in shade sheds with sprinklers do not experience heat stress until THI exceeds 78.

Hence, the THI is a standard measure of climatic stress but cows begin to experience stress depending on their particular microclimate. The amount of shade is a key factor, and each farm is different in the actual amount of heat stress their cattle will experience within a given climate. The THI thresholds at which cows start to experience heat stress can be altered by on-farm adaptation (Table 1).

Table 1: THI thresholds leading to heat stress for various management strategies, as rated by Davison et al. (1996).

Management	Poor	Average	Good	Best
Cooling strategy	Nil	Some shade	Shade at feed	Shade & sprinklers
THI threshold	72	74	76	78

In this study, we focus on the effect of heat stress on milk production as quantified by Davison et al. (1996), which is more easily quantified than effects on reproduction rates, weight loss, somatic cell counts, protein content and fat content. Milk loss for two critical THI thresholds from Table 1 is analysed:

THI > 72 milk yield starts to decline for cows with no shade
THI > 78 milk yield starts to decline for cows with shade and a sprinkler system

Following Davison et al. (1996), we calculate the number of THI units above 72 each day, then compute the annual total. After doing this for many years of daily data, we compute an annual average.

Based on the results from a number of research projects in New South Wales and Queensland, Davison et al. (1996) convert annual THI units for Muswellbrook into milk losses at a rate of 0.2 to 0.5 L/cow/THI unit. We have used the mid-value of 0.35 L/cow/THI unit in our simplified example. After multiplying average annual THI units by this value, we define THI72 as the average annual milk loss above the daily THI threshold of 72 in L/cow/year. Similarly, THI78 represents the average annual THI units above the daily THI threshold of 78 converted into L/cow/year.

Heat stress model validation

Daily maximum temperature and vapour pressure data for Muswellbrook were taken from the Queensland Department of Natural Resources data drill at http://www.dnr.qld.gov.au/resourcenet/silo/datadril.readme.html. This is a set of daily weather data that have been interpolated onto a 5 kilometre grid. Data from 1957 to 1999 from the grid-box nearest Muswellbrook were extracted, and dewpoint temperature was calculated from average temperature and vapour pressure.

This 43-year record is rather short for computing the probabilities needed in subsequent parts of this study, so the record was extended to 100 years using the LARS-WG weather generator (Racsko et al., 1991). The extended record has the same statistical properties as the original record (e.g. monthly average temperature and variance, and sequences of hot and cold days). The test for the success for this technique is to compare the results with those produced by using the historical climate.

Davison et al. (1996) published the average annual THI units above thresholds of 72, 74, 76 and 78 for Muswellbrook, allowing a direct comparison to be made. Using our extended climate record created by the weather generator, the mean annual number of units exceeding THI values of 72, 74, 76 and 78 are very close to those computed using data from the years 1957 to 1993 (Figure 3).

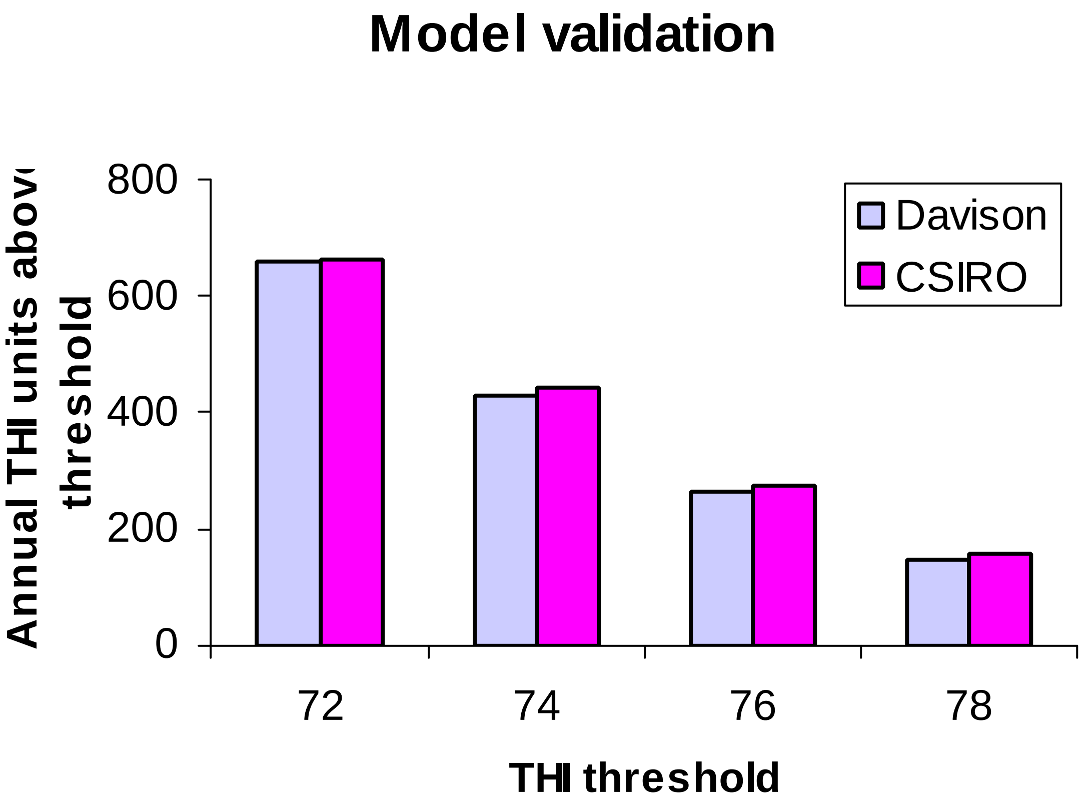


Figure 3: Annual average number of Temperature Humidity Index (THI) units above thresholds of 72, 74, 76 and 78 at Muswellbrook compared with data published by Davison et al. (1996) for 1957-1993.

Climate change probabilities

The next step is to calculate climate change probabilities for changes in maximum temperature and dewpoint temperature for Muswellbrook based on several initial assumptions about contributing ranges of uncertainty and their probability distributions.

It must be remembered that there are two types of likelihood for future events that are both measured in terms of probability. The first is event-based probability, where the likelihood of recurring events is estimated. Examples are rainfall events, floods, droughts and temperature extremes. These are often measured in return periods, which defines the average time between each event of a given magnitude. The second likelihood is the probability of a single outcome, which is measured within a range of future uncertainty. The first type of probability is associated with climate variability and extremes, and the second type of probability is used to describe the future state of climate change under the enhanced greenhouse effect. This section deals with the second type, i.e. we are trying to distinguish the probability of a single future outcome within a large range of uncertainty.

To estimate the probability of climate change, we take three types of uncertainty into account:

- future greenhouse gas and sulfate aerosol concentrations
- the sensitivity of climate to these concentrations
- regional patterns of climate change from different climate models.

To obtain conditional probabilities of a climate change based on these uncertainties, we need to quantify them as ranges with an upper and lower limit and a known probability distribution. These ranges are then sampled repeatedly and combined to determine a joint probability distribution relevant to the THI index.

The Intergovernmental Panel on Climate Change (Houghton et al., 1996) incorporates the first two types of uncertainty into their estimates of global average warming from 1990 to 2100 (Figure 4). The resultant range of uncertainty is assumed to have a uniform probability, i.e. the extremes are just as likely to occur as the central estimates. This range can be sampled at regular intervals between the lower and upper extremes to estimate the probability of a particular temperature occurring at a particular time.

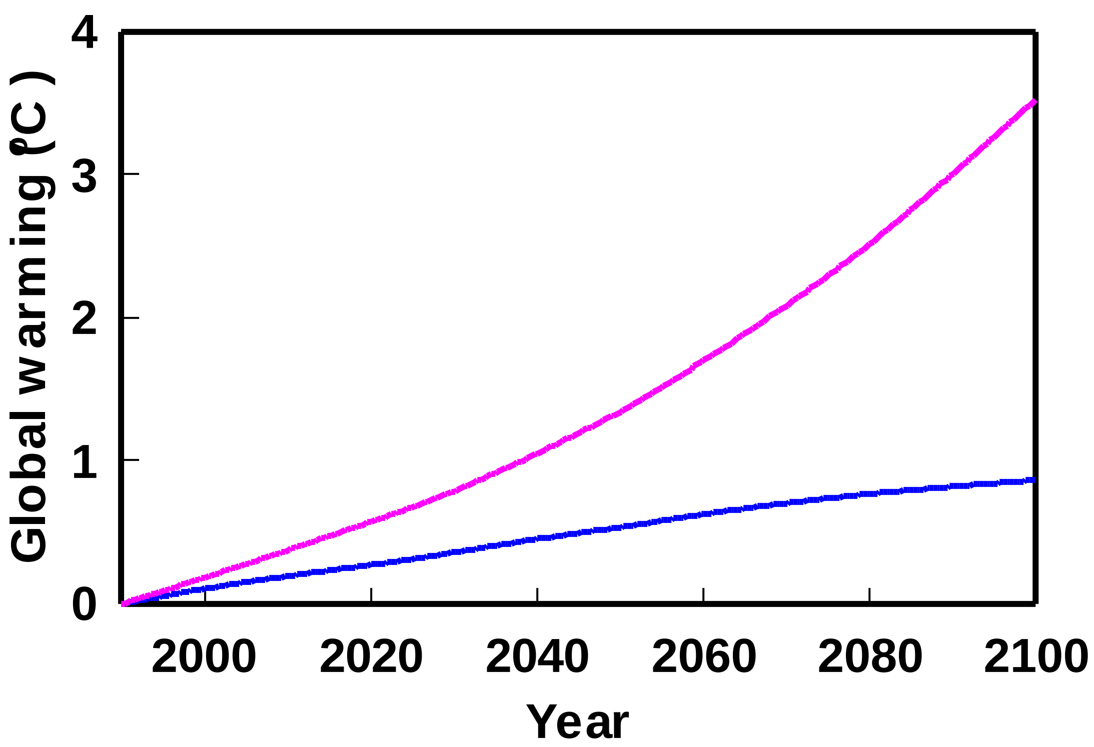


Figure 4: The range of global warming derived from IPCC emission scenarios and global warming sensitivity in Houghton et al. (1996). The upper curve is the most extreme emission scenario and climate sensitivity while lower curve is the least extreme combination.

The uncertainty due to different regional patterns of climate change from different climate models was measured by comparing the local change in maximum temperature per degree of global warming from each climate model. We did this for a fine resolution regional climate model (CSIRO DARLAM) and five coarse resolution global climate models (CSIRO Mark 2 with and without sulfate aerosol; German DKRZ ECHAM4/OPYC3; Canadian Climate Centre; and the English Hadley Centre HADCM2). The values of maximum temperature change for these six models for the Muswellbrook locality were 0.92, 0.95, 0.99, 1.02, 1.05, 1.45°C per degree of global warming. Each estimate was assumed to be equally likely with cumulative probabilities of 0, 20%, 40%, 60%, 80% and 100% respectively. This produces a non-uniform distribution with the probabilities skewed towards the lower end.

Based on model output, and a simple sensitivity analysis, a realistic range of change for local dewpoint temperature was considered to be 0 to 1.5°C per degree of global warming. This was sampled uniformly across the range.

Monte Carlo sampling (i.e. repeated random sampling) was undertaken for 10-year intervals between 2010 and 2090 in the following manner:

$$\text{Random (local } T_{max} \text{ change)} = \text{Random (global warming)} \times \text{Random (local } T_{max} \text{ change per } ^{o}\text{C of global warming)}$$

$$\text{Random (local } T_{dewpoint} \text{ change)} = \text{Random (global warming)} \times \text{Random (local } T_{dewpoint} \text{ change per } ^{o}\text{C of global warming).}$$

When sampled repeatedly for a given decade, a non-uniform distribution for both maximum and dewpoint temperatures will be built up where central values will be much more likely than the extremes. A sample result for the year 2070 is plotted in Figure 5. The shaded area describes the total range of uncertainty for local warming and dewpoint temperature change at a given time. Some climate outcomes within that range are more likely to occur than others, so their probabilities are added from the most likely to the least likely until the total is 100%. The likeliest climate outcomes, accounting for 50% of the total probability, cover less than 25% of the total uncertainty space. The least likely 5% of climates (lightest shading) take up far more of the total scenario space than the most likely 50%. This plot shows that increases of greater than about 2°C for local maximum and dewpoint temperatures by 2070 are possible, but that increases of less than 2°C are more likely.

This random sampling was repeated thousands of times to get an adequate sampling density over the projected range of uncertainty, for each of the decadal intervals from 2010 to 2090 – 2,500 times in 2010 and 2020 up to 108,000 times for 2090. At the end of the sampling periods for each decade the probability of the most likely climates to the least likely future climates were tallied to a total of 100% as shown in Figure 5.

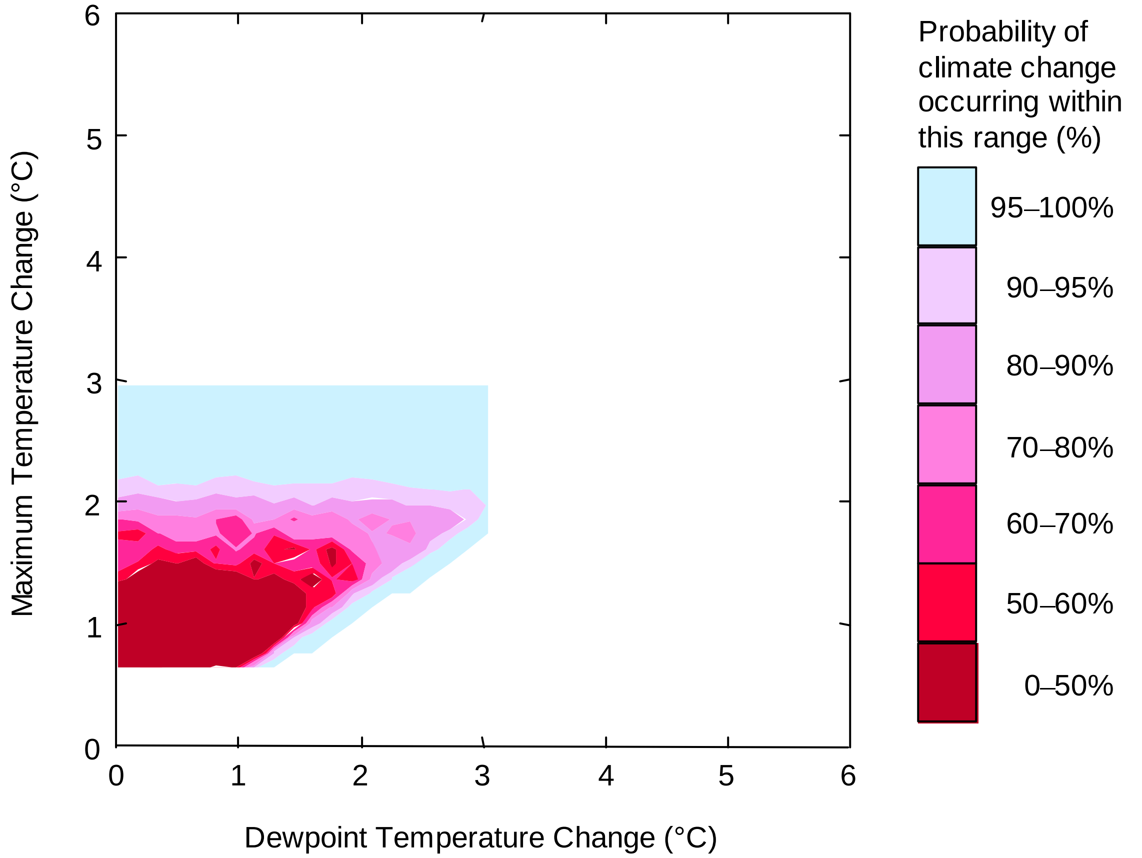


Figure 5: Probability of changes in maximum and dewpoint temperature for the year 2070 at Muswellbrook.

Risk of heat stress

To calculate the probability of heat stress exceeding given THI levels between 2010 and 2090, the Muswellbrook record of daily maximum and dewpoint temperatures was altered by each randomly sampled climate change. Daily THI for each sample was then calculated, and the average annual number of THI units exceeding 72 and 78 averaged over the 100-year record obtained. This operation was repeated for every climate sample.

To illustrate how heat stress under climate change may affect dairy cows, the THI72 and THI78 totals were converted into estimated loss of milk yield using a factor of 0.35 L/cow/THI unit. We have also converted this loss into a percentage of annual milk yield based on the following assumption. Davison et al. (1996) estimate that milk yields for New South Wales sites (including Muswellbrook, Singleton, Dubbo and Orange) average 21-22 L/cow/day – we have assumed a value of about 22-24 L/cow/day for the Hunter Valley, giving an average annual total production of 7,000 L/cow (assuming a dry period of about 40 to 70 days/cow/year). Using these assumptions, a loss of 70 L/cow/year is equivalent to a loss of 1% of potential production but these figures can be easily varied to take account of changed assumptions.

THI72 equates to a farm with poor heat stress management (see Table 1). THI78 is equivalent to the best heat stress management (shade shed and sprinklers) where loss only occurs above a THI of 78. The control (current climate) average for milk loss is 232 L/cow/year for THI72 (or 3.3% of annual production) and 55 L/cow/year for THI78 (or 0.8% of annual production). So, adapting from no shade to best shade plus sprinklers in this case would realise a 2.5% recovery in milk yield.

Figures 6 and 7 are examples of risk response surfaces that show the sensitivity of milk loss to maximum and dewpoint temperature, with climate change probabilities superimposed. The upper panel in Figure 6 shows the sensitivity of THI72 to changes in maximum and dewpoint temperatures. As mentioned, the control case is 3.3% of production. A 1°C increase in maximum temperature with no change in dewpoint temperature will raise this loss to 280 L/cow/year or 4% of current production. A similar effect occurs for a 2.8°C increase in dewpoint temperature with no change in maximum temperature. The sensitivity surface shows potential losses of up to 10% for the ranges shown in the diagram. The lower panel shows sensitivities for THI78, which range from just less than 1% to over 4%.

When superimposed onto climate probabilities for 2030, Figure 6 shows that milk loss for THI72 approaches 280 L/cow/year or 4% of current production, up from the control case of 232 L/cow/year. The THI78 case shows that best management restricts losses to about 70 L/cow/year or 1% of annual production. However, the difference between the THI72 case and the THI78 case represents the savings possible through improved management – savings range from 190 to 220 L/cow/year, or 2.7% to 3.2% of annual production. This shows that if adaptation to heat stress shows economic benefits under current conditions, these benefits will be greater in 2030 if the relationship between costs and gross return does not change significantly.

Figure 7 shows the same two relationships for the year 2070. Several factors are obvious. Firstly, the projected ranges of climate change and the resultant uncertainty are much larger. The most likely climates occur in the range 250 to 400 L/cow/year loss for THI72, with less likely climates exceeding 420 L/cow/year, or 6% of annual production. Heat stress management is much more attractive by 2070, reducing the milk loss to 60 to 120 L/cow/year. Assuming a milk price of 25c per litre, this is worth $5,700 to $8,400 per year for a herd of 120 cows.

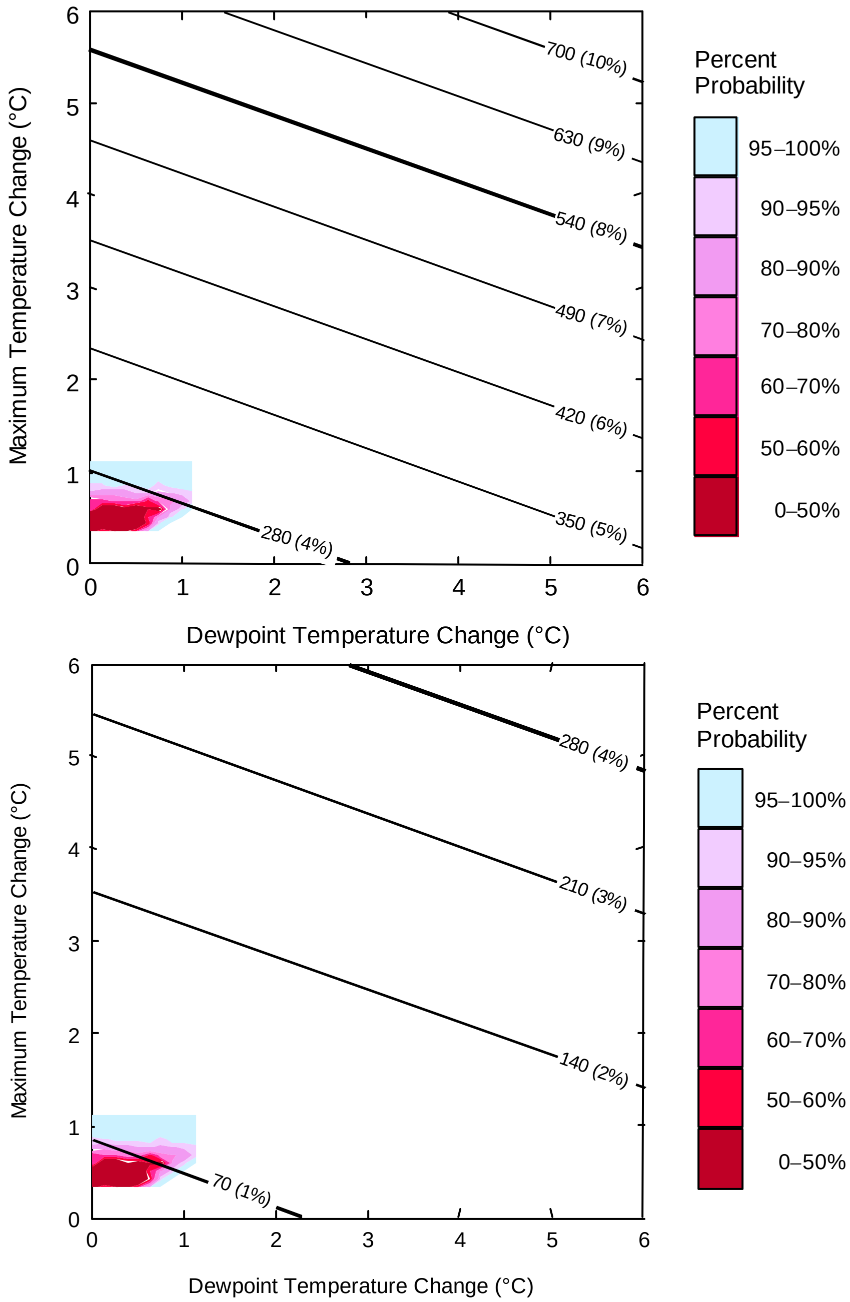


Figure 6: Milk loss (sloping lines: litres (% of annual production)) in response to changes in maximum temperature and dewpoint temperature for poor (THI72 no shade and sprinklers: upper panel) and best (THI78 shade and sprinklers: lower panel) heat stress management. Climate change probabilities for the year 2030 are superimposed in colour.

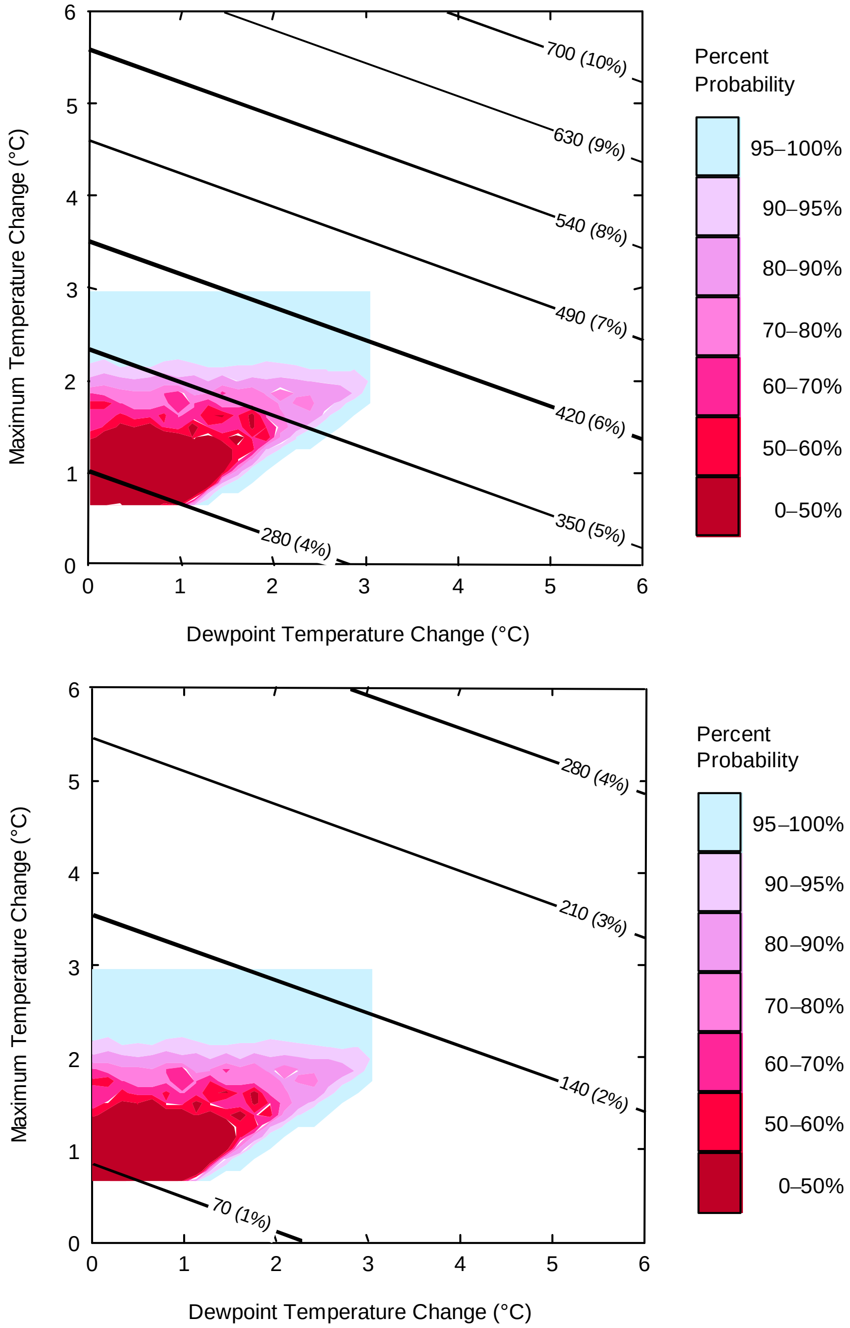
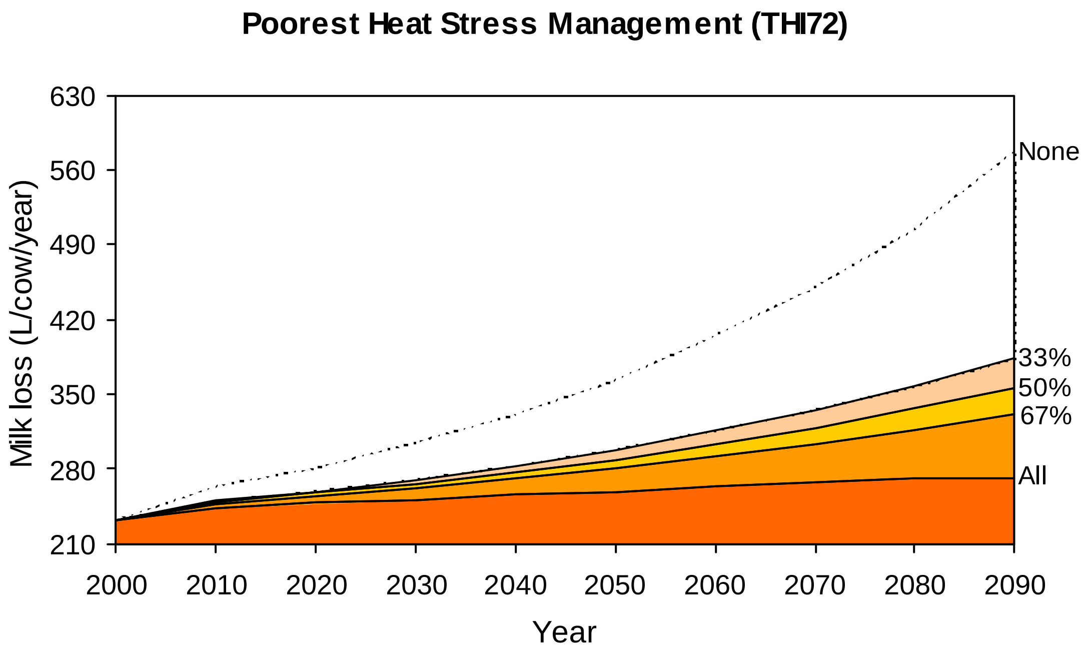


Figure 7: Milk loss (sloping lines: litres (% of annual production)) in response to changes in maximum temperature and dewpoint temperature for poor heat stress management (THI72 no shade or sprinklers: upper panel) and best (THI78 shade and sprinklers: lower panel) heat stress management. Climate change probabilities for the year 2070 are superimposed in colour.

To estimate the probability of milk losses due to climate change we sum the probabilities of all climates falling below a given level of annual average milk loss. For example, if we wished to know the probability of a loss greater than 350 L/cow/year in Figure 6, we would sum the probability of all climates falling below the 350 L/cow/year line. In this way the probabilities of all values of milk loss for the decades 2010 to 2090 were calculated (Figures 8 and 9).



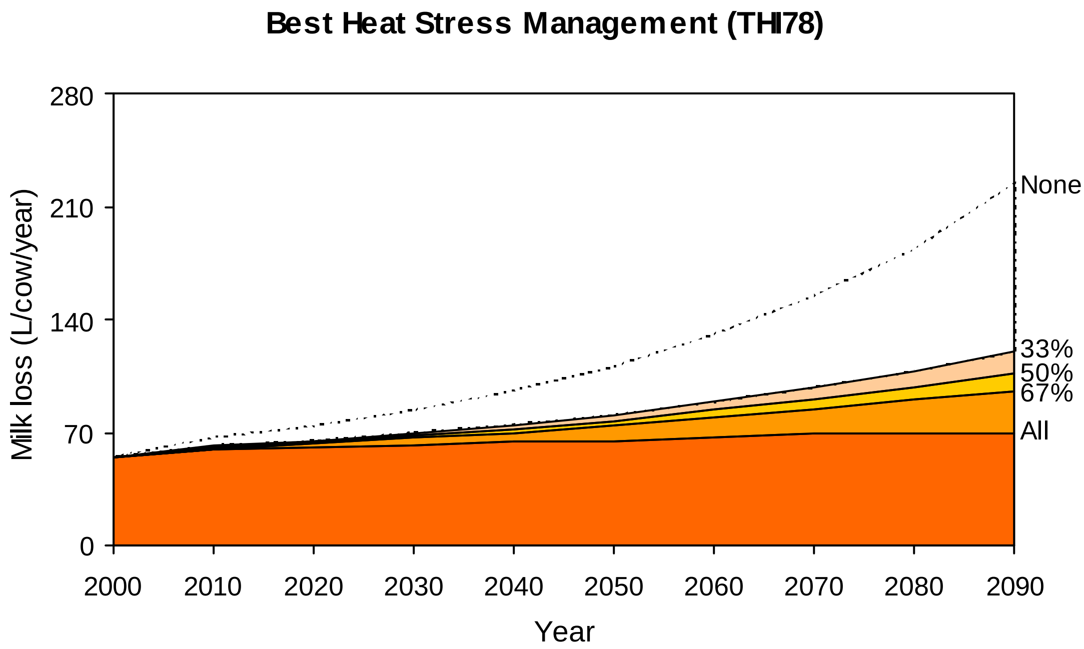


Figure 8: Comparison of simulated milk loss from poor heat stress management (no shade or sprinklers) and good heat stress management (shade and sprinklers) for dairy cattle at Muswellbrook. The values on the right refer to the risk of milk loss values below that line. Note the difference in vertical scale in each plot.

The upper panel of Figure 8 shows the likelihood of rates of milk loss in L/cow/year for THI72. The 100% limit shows the minimum loss due to occur under all projected climate changes, i.e. the minimum loss that may be expected averages 230 L/cow/year under current climate, rising to about 270 L/cow/year in 2090. The 67% level marks the level that accounts for two-thirds of possible future climatic states, i.e. in two-thirds of all projected climates in 2090 milk losses would exceed 330 L/cow/year, while in only one third of climates, would milk losses be less than 330 L/cow/year. These latter probabilities account for climates with low climate sensitivity and low greenhouse gas emission rates.

At the 50% level, the rate of milk loss is over 355 L/cow/year and in one third of future climates the rate of milk loss increases to over 380 L/cow/year. The least likely climates are associated with the greatest losses. For instance, in 2090 average milk loss may exceed 560 L/cow/year, although this is very unlikely. The lower panel of Figure 8 shows losses for THI78, accounting for farms where heat stress is well managed. Projected losses are fairly modest over most of the next century, remaining at 1–2% of total yields under most climates. This indicates that current practices will be suitable for adapting to future climates if the economics of heat stress management do not change radically. Figure 9 shows the benefits of managing heat stress by improving from THI72 to THI78 between now and 2090 (the difference between the upper and lower plots in Figure 8). Productivity gains (measured as a reduction in potential milk loss) of up to 350 L/cow/year may be possible by the end of the century.

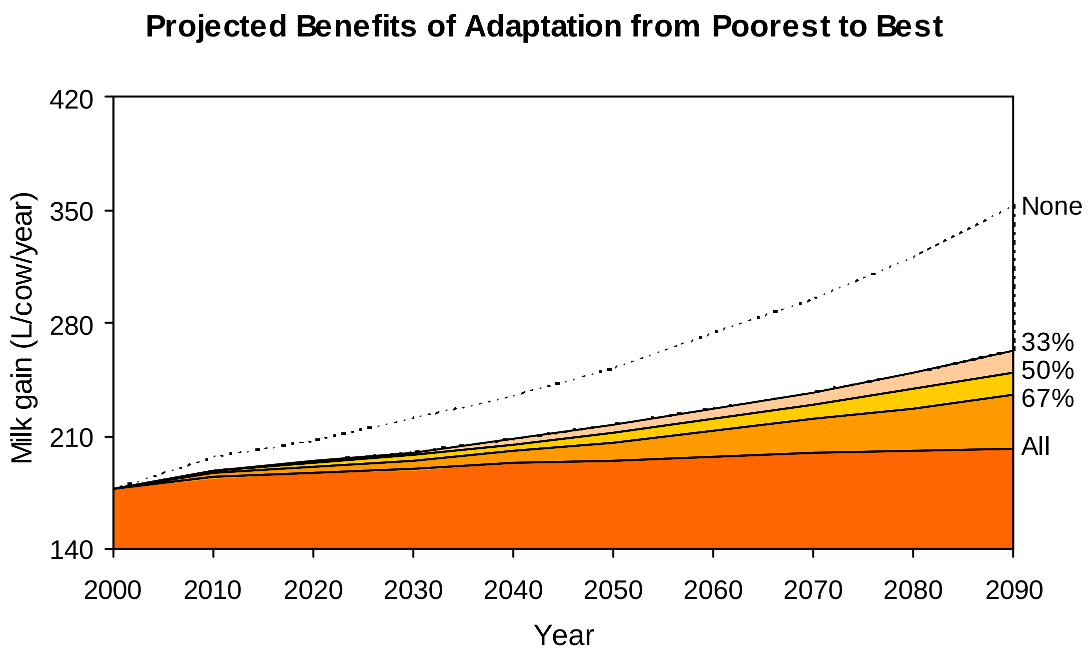


Figure 9: Difference in simulated milk loss between poor and best heat stress management (THI72-THI78) for dairy cattle at Muswellbrook, i.e. the benefit of installing shade and sprinklers. The values on the right refer to the risk of milk loss values below that line due to climate change. Every 70 L represents 1% of annual milk production.

Economic implications and adaptation options

Davison et al. (1996) describe a cost benefit analysis that can be updated so that an individual farmer can assess his or her potential losses and gains from adaptation. The uncertainties involved in such an exercise include the rate of milk loss measured in L/THI unit, summer price of milk and the costs of adaptation. The exposure of a property to heat stress and losses in milk yield will vary from farm to farm. A full cost benefit analysis for the Mutdapilly Research Station in Queensland takes into account infrastructure costs, finance costs, depreciation, extra feed, extra milk production costs and operating costs, while the benefits include higher milk returns, higher breeding rates, lower breeding costs and greater stock value.

To work out the annual cost of milk loss that might be recovered by installing shade and sprinklers, we need to know the difference between the cost without shade or sprinklers (annual THI units above 72) and the cost with shade and sprinklers (annual THI units above 78). For the current climate, if the rate of milk loss is 0.35 L/THI unit, and the summer price of milk is 25c per litre, an increased gross return of about $44 per cow per year could be expected when adapting from THI72 to THI78. From figures in Davison et al. (1996), the capital, financing and depreciation costs of erecting full shade and sprinklers is about $30 per cow per year. This indicates a gross return of $14 per cow per year in the current climate. This is not a full cost benefit analysis as increased feed costs, and the financial benefits from more efficient breeding, which are more or less equal for different cooling options (Davison et al., 1996), are omitted. Although a full cost benefit analysis will differ from farm to farm, these figures indicates that heat stress management in the Muswellbrook area will be cost effective.

Under climate change, these adaptations will continue to be effective. Based on current costs, the benefits for 2030 and 2070 are shown in Table 2. As costs and benefits are likely to change substantially in the future this should only be taken as a general guide to how adaptations to heat stress may apply over the next century.

Table 2: Provisional economic benefit ($/cow) of installing shade and sprinklers for various levels of climate change probability in the years 2030 and 2070 at Muswellbrook.

Year	Probability	Benefit	Probability	Benefit	Probability	Benefit
2030	100%	$17	67%	$19	33%	$20
2070	100%	$20	67%	$25	33%	$29

Feedback from stakeholders

To gauge the usefulness of the analysis presented in this report, and to determine how to proceed with further impact assessments in the Hunter Valley, a report-back workshop was held by CSIRO in Newcastle on 22 December 1999. About 30 stakeholders from the following agencies attended:

- NSW Cabinet Office
- NSW Health
- NSW Department of Urban Affairs and Planning
- NSW Environment Protection Authority
- NSW State Forests
- NSW Department of Land and Water Conservation
- NSW Minerals Council
- NSW Agriculture
- NSW Dairy Farmers Association
- Nature Conservation Council of NSW
- Hunter Regional Organisation of Councils
- Hunter Catchment Management Trust
- University of Newcastle
- Newcastle City Council
- Hassall and Associates

CSIRO presented the results of the risk assessment detailed in this report. Probabilistic estimates of impacts within a range of uncertainty were seen as an improvement on methods that simply give an upper and lower bound for impacts. The participants felt that this is a format useful for both planning and policy that is compatible with the many other uncertainties they face. However, given the emphasis on probability analysis, one stakeholder noted that risk management models for industry sometimes use general information rather than quantitative solutions.

Most of the plenary session involved discussion of other issues that might be addressed in a subsequent impact study. The main issues identified by three working groups at the May 1999 workshop were summarised (Hennessy and Jones, 1999):

1 Catchment-scale impacts
   - Integrated understanding of catchment flows – upland to estuaries
   - Disturbance events, e.g. fire, drought and flood
   - Flora and fauna – species and community distribution

2 Primary industry impacts
   - Thermal stress
   - Climate seasonality
   - Water availability and quality.

3 Urban and industrial impacts
   - Power generation
   - Water supply

- Rural settlements.

All three working groups nominated water supply as a key issue. Most of the water-related thresholds are associated with climate variability and extremes, and/or involve several factors, e.g. extreme flow rates (droughts and floods) and irrigation supply (stream flow, water storage and groundwater supply).

In the plenary session of the December 1999 workshop, the links between variables identified in the May workshop were discussed further. CSIRO presented a diagram (Figure 10) showing the sensitivity of Hunter Valley processes and activities to environmental forces, based on the results of a cross-impacts analysis. In Figure 10, "forcing" refers to the ability of a variable to act as an agent of change. Dependent variables are those that respond to change. Variables in the upper left hand corner of Figure 10 are those that show strong external forcing, in this case due to climate change, with little dependency, e.g. these variables cause change in the Hunter Valley but are not changed themselves by the Hunter Valley. Moisture-related climate variables stand out as the strongest drivers. Those in the lower left-hand quadrant labelled "autonomous" may be important in specific cases but are not significant from a systems point of view. Those in the upper right are relay variables that are strongly dependent on external forcing but also force other variables. These variables are likely to exhibit strong feedbacks. On the lower right of Figure 10 are the dependent variables that show a wide sensitivity to both climate and to catchment processes such as land-use and catchment condition. These are often variables that are a measure of environmental quality, particularly water quality, and are the subject of environmental monitoring and reporting. They are also the most vulnerable.

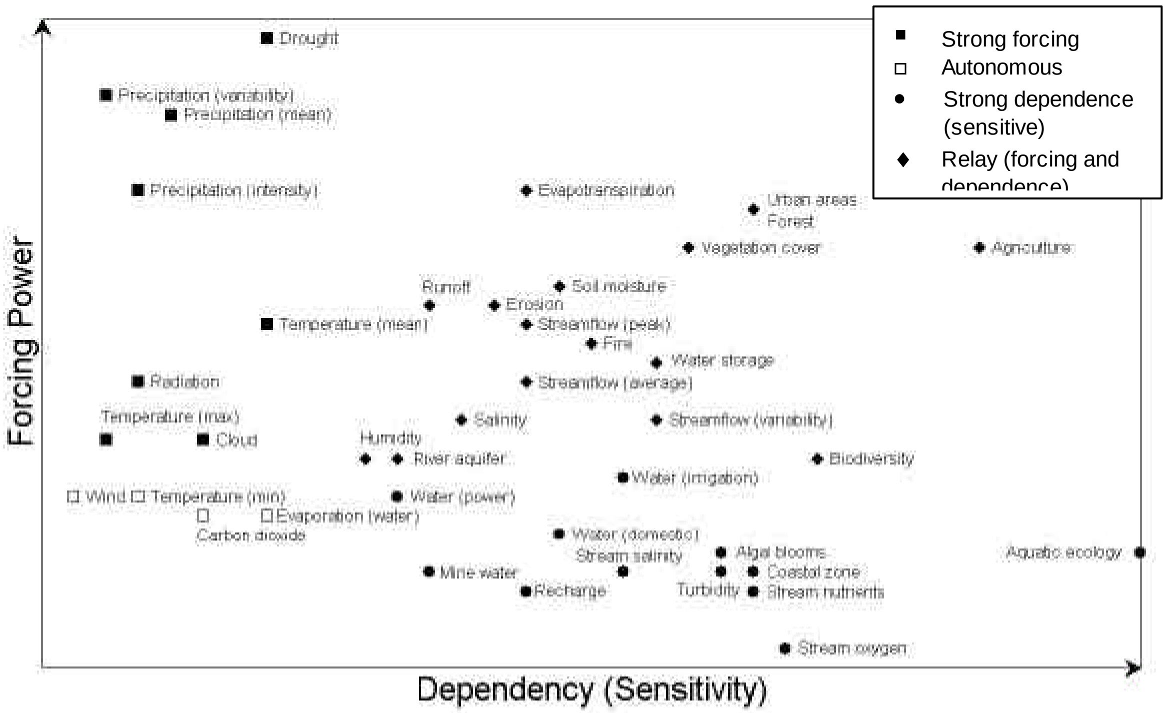


Figure 10. Forcing/dependency chart for climate, catchment processes and catchment-based activities in the Hunter River Valley. Forcing is a measure of the ability to cause change, dependency is a measure of the response to change.

Given the strong dependence of regional issues (such as water quality, biodiversity, agriculture, urban areas, forests and the coastal zone) on water-related factors (such as precipitation, runoff, soil moisture and streamflow), participants in both the May and December 1999 workshops appreciated the value of linking regional climate change modelling with regional hydrological modelling. However, the complexity of such an undertaking precluded it from the pilot study (Hennessy and Jones, 1999) as it requires scenarios for both rainfall and evaporation, and utilises much more complex models than the simple heat stress relationship for cattle.

To assess the effect that changes in hydrology might have on regional activities and processes, a number of stakeholders recommended a "systems approach". This enables the integration of links and feedbacks between climate-dependent issues like biodiversity, agriculture, forestry and urban planning. Such an approach has already been detailed in an unpublished report to the NSW Climate Adaptation Steering Committee. Figure 10 is taken from that report. Hydrological modelling is a discipline in which there is strong local expertise, and the May workshop demonstrated a high level of awareness of the activities and processes that would be needed in an integrated assessment for the Hunter Valley. An example of an integrated assessment of water supply in the Macquarie River catchment, produced changes in water supply, gross economic agricultural production and return periods for waterbird breeding events (Hassall and Associates et al., 1998).

Several barriers to the utility of impact assessments were identified. Some stakeholders noted that economic rationalism drives many planning processes and that cost-benefit analyses were needed to endorse arguments for change. Performing cost-benefit analyses for climate change impacts remains a huge challenge, particularly for low-risk but high-impact extreme events, impacts on biodiversity and intangible impacts such as trauma. Another barrier to the usefulness of impact assessments is the broad range of uncertainty. Some stakeholders felt that more precision would be required before impact assessments were taken seriously. For instance, it was noted that the inclusion of economics adds another layer of uncertainty but stakeholders could act jointly to manage the uncertainty in their own areas of expertise.

To help sell the idea of adapting to climate change, it was suggested that an emphasis on "no regrets" measures and the "precautionary principle" would be seen as a way of adding value to existing planning processes. Identifying big issues with high political and public sensitivity, such as the critical river flow required by Macquarie Power for Sydney's minimum power supply, was also viewed as a way of attracting attention to the importance of adaptation and planning.

Where to from here?

The consensus from the December 1999 workshop was that CSIRO's risk assessment approach is useful and could be applied in a more detailed impact assessment. Stakeholders considered a valuable next step could be to estimate the effect of climate change on hydrology in the Hunter Valley, with a view to eventually doing an integrated assessment of impacts on processes and activities dependent on hydrology. This would be a major project involving much greater technical complexity than the heat stress example. The climatological uncertainties remain large but the hydrological expertise is well developed. However, the application of these factors to the impacts outlined in Figure 10 in an integrated risk assessment would require extensive collaboration by both technical and stakeholder interests.

Applying the methodology applied in this report, regional probabilities for rainfall and evaporation change would be needed to drive a rainfall-runoff model of the Hunter River Catchment. Such a model does exist: the IQQM model written and operated by NSW Department of Land and Water Conservation (DLWC). A collaborative project involving CSIRO, DLWC and Hassall and Associates funded by the Rural Industries Research and Development Corporation is applying this method to the Macquarie River catchment in northeast NSW. The threshold currently being investigated is historical average streamflow. Figure 11 shows the type of output envisaged for that project. Note that this does not illustrate actual output but is intended to communicate the type of output being aimed for. The output from catchment management models such as IQQM also includes peak flow, flow distribution, supply at various points and water quality. These types of output can be used to address critical thresholds, as outlined in Hennessy and Jones (1999) and to provide input for economic and production models.

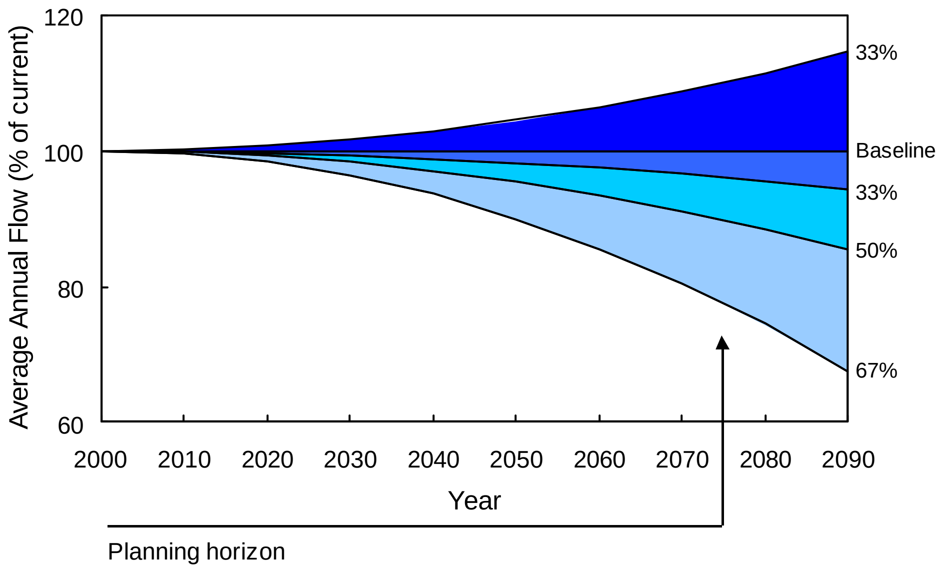


Figure 11. Schematic relationship between change in average annual streamflow and risk under climate change envisaged by applying a risk assessment method to a rainfall-runoff model.

An integrated project utilising the risk assessment methodology would be a complex undertaking requiring financial resources in addition to a substantial input of time and effort from the various regional stakeholders. However, many of the technical difficulties are being overcome. An outstanding goal is to ensure that outcomes with a high degree of uncertainty can be assessed and communicated in such a way that they are consistent with each other, and have utility for long term planning and policy. This remains the largest, as yet unrequited aim of CSIRO's risk assessment framework.

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Climate change data from the German, Canadian and English climate models were supplied by the IPCC Data Distribution Centre.

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