final report

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Revision of the Risk Analysis Program

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1. Introduction

Katestone Environmental was commissioned by EA Systems in 2004 to develop a Heat Stress Risk Analysis Program (RAP) on behalf of the Meat & Livestock Australia Limited (MLA). The RAP was developed to assist feedlot operators to determine whether potential feedlot sites are suitable.

The program was developed initially to quantify the heat stress at potential feedlot sites using the meteorological data collected from various Bureau of Meteorology monitoring stations in Australia. The 2004 version of the RAP included meteorological data from 56 selected sites and the meteorological data was screened to remove obvious erroneous data from the files.

Since 2004, the feedlot operators have found the RAP to be useful and have requested that the RAP include more locations. The latest version of the RAP has a total of 48 sites. MLA also requested that further analysis of the data be undertaken to consider the following:

- Investigate the effects of climate change in selecting a suitable dataset to adequately represent the potential future risk;
- Suitability of data in terms of accurately representing the climate at the location;
- Investigation of possible methods for extending the data sets at sites with limited years of data;
- Scrutiny of heat stress events and comparison of sites to ensure accuracy of risk calculated.

Along with these changes required for the RAP, further studies have been conducted by MLA to refine the susceptibility of various breeds of cattle to high heat load.

This report covers the above issues and also the following:

- Investigation of dataset length required to ensure risk generated for a site is representative of possible future impacts due to climate change.
- Sites included in the RAP and methods used to analyse and calculate the risk.
- Comparison of old and new RAP.
- Updated HLI thresholds included in the RAP.
- New delivery mechanism for RAP on the web.
- New HLI and AHLU calculators on the web.

2. Overview of climate change

Greenhouse gases such as carbon dioxide have been implicated in global climatic changes. Greenhouse gases affect the balance between incoming solar energy and losses due to radiation from the earth and atmosphere. The global atmospheric concentration of carbon dioxide has increased from a pre-industrial level of 280ppm to 379ppm in 2005 (IPPC, 2007). This increase in greenhouse gases has important implications for increasing temperatures and other climatic effects. The affect of climate change on heat load has obvious implications for the RAP.

The International Panel on Climate Change (IPCC) and Australian organisations such as the CSIRO have confirmed that climate change is occurring, particularly over the past 30 years and have developed models to forecast the impact on the climate that could occur over the next 30-70 years.

The IPCC has shown that, globally, the daily maximum temperatures increased between 1950 and 1993 at a rate of 0.1°C per decade while the daily minimum temperature increased at a rate of 0.2°C per decade (IPCC, 2001). The IPCC has projected that the average global temperature could increase at an average rate of 0.14 ºC per decade over the water and at greater rate over land.

The CSIRO confirms the IPCC results stating that the Earth has warmed on average by 0.6±0.2ºC since 1900 (CSIRO, 2001a). The CSIRO has estimated that the average temperature increase over Australia between 1910 and 1999 has been around 0.7 ºC, with most of this change occurring since 1950. The CSIRO projections for Australia are for an increase in the annual average temperatures of 1 to 6 ºC by 2070 with slightly smaller increases in Tasmania and some coastal areas. The degree of warming is projected to be greatest in spring and least in winter. The CSIRO has also forecast that the increase in the daily maximum and minimum temperatures will be similar to the increase in the average temperatures.

Whetton et al (as part of Bouma et al 1996) details the CSIRO studies further to provide a breakdown of the projected degree of global warming in regions within Australia. These studies indicate that by 2030 the degree of temperature change in Australia varies by 0-1.5 ºC in the northern coast, 0.5-2.0 ºC in the southern coast and by 0.5-2.5 ºC in inland Australia. These studies also noted a change amount of variability in the climate change with location and season. In the northern coastal areas a greater degree of warming was noted in spring (similar to the CSIRO study (CSIRO, 2001a).

2.1 Impact for the agricultural industry

The potential impact of climate change on the agricultural industry has been studied in detail by the CSIRO. The CSIRO predicts that the major impact of climate change on the agricultural industry in Australia is an increase in pests and weeds and therefore potentially a decrease in plant and animal production. Production is also likely to be affected due to the expected decrease in rainfall as a result of climate change (CSIRO, 2001b).

In relation to the RAP, the main question is how will climate change impact cattle heat stress? Howden et al (1999) conducted a study into the impact of climate change on the frequency of cattle heat stress events for the Australian Greenhouse Office. This study involved calculating the heat stress in cattle using the Temperature-Humidity Index and assessing the frequency of events above a threshold of 80. This study was conducted using a model developed by the CSIRO that covers the entire area of Australia. The study quantified heat stress for the years from 1957 to 1997. The model was rerun to calculate the heat stress in cattle for an increase in temperature due to global warming of 2.7ºC. The outcome of this assessment was that heat stress would be significantly higher in the northern half of Australia and much lower in the southern half of Australia. Very little change in heat stress events was found in the southern tips of Western Australia and Victoria and throughout Tasmania.

2.2 Analysis of existing monitoring data

To determine whether the monitoring data for sites included in the RAP show a warming trend, three long-term monitoring sites were analysed. Although analysis of long datasets of 100 years or more would be ideal there are some difficulties and potential errors to be addressed. Over a long period of time the monitoring equipment can be changed, calibrated differently, the environment around the monitoring station may have changed or the station actually moved. For these reasons, as well as the reliability of the data, the daily minimum and maximum temperatures have been reviewed at Wagga Wagga, Amberley and Albany for the period from 1985 to 2005. The data capture rate for these sites was 100% in this period.

The data was divided into seasons and the average daily minimum and maximum temperature for each year was calculated. A trendline was then added to these data. A time-series of these measurements is presented in Appendix 1. Table 1 presents a summary of the information included in these figures.

Each of the sites analysed show different results with the Wagga Wagga and Amberley sites suggesting some degree of warming, possibly even higher than that indicated by the CSIRO and IPCC. However, the Albany site shows no obvious increase in temperatures. Whettan et al (as part of Bouma et al 1996) indicates that seasonal variability in the extent of warming is expected.

Table 1: Summary of temperature changes from 1985 to 2005 in three different locations in Australia.

Season	Wagga Wagga (NSW)	Amberley (Qld)	Albany (WA)
Summer	Increase of around 2°C in maxima and around 1°C in minima	Increase of around 0.5°C in maxima and minima	Decrease of around 0.5°C in maxima and increase of around 0.5°C in minima
Autumn	Increase of less than 1°C in maxima and decrease of 1-2°C in minima	Increase of around 1°C in maxima and decrease of around 1°C in minima	Increase of around 0.5°C in maxima and no obvious change in minima
Winter	Increase of nearly 2°C in maxima and less than 1°C in minima	Increase of around 1°C in maxima and decrease of around 0.5°C in minima	No obvious change in maxima or minima
Spring	Increase of around 1°C in maxima and minima	Increase of around 1°C in maxima and around 0.5°C in minima	Very little change in maxima and minima

2.3 Implications for RAP

Studies from the CSIRO and IPCC show that warming has occurred over the past 50 years and temperatures are projected to increase further in the future.

The HLI is a measure of heat load that was developed by MLA. If the temperature were to increase by 1-6°C by 2070 as predicted by CSIRO (2001a) the HLI would increase by 1.7-8.4 points. Depending on what time of day the temperature increase occurs the impact on accumulated heat stress in cattle could be varied. A significant increase in maximum temperatures during the day and night could have a large impact on the AHLU. The impact of reduced rainfall is unclear but one possible outcome is a reduction in relative humidity, due to less moisture available. This would have a positive impact on the heat stress levels, as a 10% decrease in relative humidity decreases the HLI by almost 4 points. The frequency of events is also an important factor that would need to be taken into account to fully assess the impacts of future climate change on the heat stress in cattle.

The long-term (> 20 years) implications of climate change for the RAP are quite clear. The monitoring data that is available from the last ten years is unlikely to be indicative of the longer-term risk of heat stress. For the next 20 years, the situation is less clear. In most parts of Australia the monitoring data from the last 10 years shows the influence of warming. The use of this data in the RAP is likely to bias the estimates of potential heat stress towards the higher range of likely outcomes than would be the case if more historic data were included. Future versions of the RAP should revisit this issue.

3. Meteorological data verification

3.1 Initial verification

The data collected at each of the sites was initially screened to remove any obvious erroneous data. This included the following:

- Removal of temperature and dew point temperature measurements that were below –20°C or above 60°C.
- Removal of relative humidity measurements outside the range of 0-105%. Although measurements above 100% are incorrect, values slightly above 100% can be recorded from a slightly uncalibrated instrument.
- Wind speed was screened to ensure all winds were between 0 and 40 m/s (144 km/h).
- Wind directions from 0 to 360°.

Once the data was screened, time-series plots for each parameter for each site were generated to indicate any obvious anomalies in the data, such as:

- Problems with the monitoring equipment (e.g. relative humidity values consistently between 95 and 100% for several days).
- Annual and daily profiles of the data were consistent between sites and follow the normal profiles such as temperature peaks during the hours 11 am to 4 pm and temperature increasing in summer and decreasing in winter.
- Consistency of meteorological measurements between years. Although some degree of interannual variability will occur, discrepancies can occur due to a problem with the meteorological monitoring equipment – particularly if the equipment is faulty.

From these analyses the following issues were identified:

- Katanning – data only included from the year 2000 as the wind speed was found to be erroneous prior to 2000.
- St Lawrence – This site had 3 hourly observations but was missing midnight. The data contains a significant proportion of calm winds which is increased when linear filling the measurements to hourly. Filling the data in a linear fashion from 9 pm to 3 am was found to overestimate the temperature as the temperature decreases quite rapidly after 9 pm (as found with comparative sites and hourly temperature profiles). As a result of these problems with the data this site was not included in the RAP.
- Goondiwindi – This site had 3 hourly observations and was found to record 24 % of the measurements as calm winds. The winds were also found to be significantly different between years with the first few years from 1995 different to the last few years. The site was also decommissioned in 2004. As a result of these problems, this site was not included in the RAP.
- Emerald – The wind speed measurements recorded at this site during the year 2000 was identified to be significantly different to other years. The site recorded 17% calm winds during the year 2000 compared with 2% over the other years of monitoring. As this year was significantly different the year 2000 data was removed from the dataset.
- Amberley – The wind speed recorded prior to June 1997 was significantly different to data collected after this period. Compared to post June 1997 and other nearby sites, the winds prior to June 1997 were considered unrealistic and were removed from the dataset.
- Toowoomba – Hourly data were recorded from 1997 when an automatic weather station was installed. Comparing the data pre 1997 to post 1997 found the wind speed sensor

gave very coarse, inaccurate measurements pre 1997. Therefore data collected from 1997 was included in the RAP.

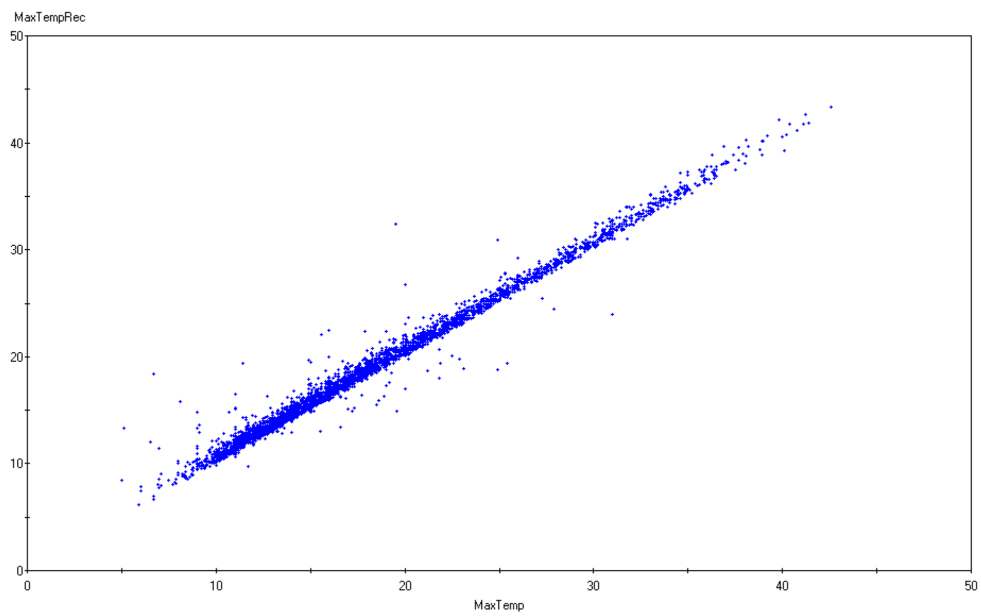
- Southern Cross – Although this station has been operating for several years only one full year of consistent measurements was available. Basing a heat stress risk on one year of data only was considered unreliable and this site was therefore not included in the assessment.

3.2 Comparison of the alternate minimum and maximum daily temperature measurements at each site

Temperature is an important parameter in the HLI and therefore it is critical to ensure that the data used in the RAP are correct. Several decades ago, the Bureau of Meteorology recorded only the daily maximum and minimum temperatures at several locations in Australia. The instruments that were used were very robust and different to the temperature probes that are used to record the hourly measurements in the automatic weather stations. The daily maximum and minimum temperatures from theses older monitoring locations were compared with the daily maximum and minimum temperatures calculated from the automatic weather stations for each of the sites included in the RAP.

Figure 1 shows a plot of the daily maximum temperature (MaxTemp) versus the daily maximum temperature calculated from the hourly data (MaxTempRec). Minor differences are shown due to the automatic weather station sensor temperature measurement based on an hourly average while the daily maximum temperature probe can be based on an instantaneous measurement. The high correlation between the measurements indicates the daily maximum derived from the hourly AWS data are sufficiently accurate for the purpose of the RAP.

Figure 1: Scatter plot of daily maximum temperature at Hamilton from different recording devices.



3.3 Available data

The 48 monitoring sites included in the RAP are presented in Table 2 along with the number of years of data that has been included in the RAP. There were a number of additional sites analysed and due to various reasons were excluded from the RAP. The reasons for excluding a site included insufficient data, errors with one or more parameters or the data were not considered to be representative of the area. A total of 17 new sites have been added to the RAP and nine sites previously included in the RAP were removed.

Table 2: Summary of data available from each of the Bureau of Meteorology monitoring stations included in the RAP (48 sites in total).

Site name	Location (latitude, longitude)		State	Start date	End date	Averaging period	Years of data
Albany Airport	-34.941	117.802	WA	1/01/1995	26/07/2006	1-hour	11.6
Albury	-36.069	146.951	NSW	1/01/1995	26/07/2006	1-hour	11.4
Amberley	-27.629	152.711	QLD	1/06/1997	7/08/2006	1-hour	9.0
Armidale Airport AWS	-30.527	151.616	NSW	1/01/1995	5/11/2004	3-hour	9.5
Ayr*	-19.617	147.376	QLD	24/03/1997	26/07/2006	1-hour	8.9
Bendigo*	-36.74	144.325	VIC	1/01/1995	26/07/2006	1-hour	10.8
Bridgetown	-33.949	116.131	WA	7/07/1998	26/07/2006	1-hour	7.9
Bundaberg*	-24.905	152.317	QLD	7/11/1998	26/07/2006	1-hour	7.7
Casino Airport AWS	-28.878	153.052	NSW	20/07/1995	26/07/2006	1-hour	10.8
Clare	-33.823	138.594	SA	1/01/1995	26/07/2006	1-hour	11.3
Cleve	-33.708	136.503	SA	7/07/1996	26/07/2006	1-hour	9.9
Cobar*	-31.539	145.796	NSW	1/01/1995	26/07/2006	1-hour	11.3
Condobolin	-33.068	147.213	NSW	3/02/1997	26/07/2006	1-hour	9.4
Coonamble	-30.978	148.38	NSW	17/09/1997	26/07/2006	1-hour	8.8
Deniliquin*	-35.56	144.944	NSW	23/05/1997	26/07/2006	1-hour	9.1
Dubbo	-32.221	148.575	NSW	1/01/1995	26/07/2006	1-hour	11.3
Emerald	-23.569	148.176	QLD	1/11/1998	26/07/2006	1-hour	6.7
Geelong	-38.224	144.334	VIC	20/02/1999	26/07/2006	1-hour	7.4
Glen Innes	-29.678	151.694	NSW	1/01/1997	26/07/2006	1-hour	9.4
Griffith*	-34.249	146.07	NSW	13/06/2000	26/07/2006	1-hour	6.1
Hamilton*	-37.649	142.064	VIC	2/05/1995	26/07/2006	1-hour	10.4
Hay CSIRO	-34.547	144.867	NSW	1/01/1995	26/07/2006	1-hour	10.9
Katanning	-33.686	117.606	WA	1/01/2000	26/07/2006	1-hour	6.1
Mackay*	-21.171	149.179	QLD	12/10/1995	26/07/2006	1-hour	10.6
Morawa*	-29.205	116.023	WA	25/02/1997	26/07/2006	1-hour	8.9

Site name	Location (latitude, longitude)		State	Start date	End date	Averaging period	Years of data
Moree	-29.491	149.846	NSW	17/05/1995	26/07/2006	1-hour	11.1
Mount Lofty*	-34.976	138.708	SA	1/01/1995	26/07/2006	1-hour	11.3
Mudgee	-32.562	149.616	NSW	1/01/1995	26/07/2006	1-hour	11.4
Naracoorte	-36.981	140.727	SA	17/06/1998	26/07/2006	1-hour	8.0
Newdegate	-33.113	118.84	WA	29/05/1996	26/07/2006	1-hour	9.0
Nullo Mountain*	-32.726	150.228	NSW	1/01/1995	26/07/2006	1-hour	11.3
Oakey	-27.404	151.741	QLD	1/09/1996	26/07/2006	1-hour	9.6
Orange	-33.381	149.127	NSW	1/01/1995	26/07/2006	1-hour	11.3
Parkes	-33.129	148.242	NSW	1/11/1997	26/07/2006	1-hour	8.7
Rockhampton*	-23.377	150.476	QLD	12/10/1995	11/07/2006	1-hour	10.7
Roma	-26.546	148.777	QLD	24/03/1997	26/07/2006	1-hour	6.6
Scone*	-32.037	150.83	NSW	1/01/1995	26/07/2006	1-hour	11.4
St George	-28.049	148.594	QLD	2/03/2000	26/07/2006	1-hour	6.2
Stanthorpe	-28.621	151.953	QLD	24/03/1997	26/07/2006	1-hour	9.1
Strathalbyn*	-35.286	138.894	SA	14/05/1996	26/07/2006	1-hour	9.9
Tamworth	-31.079	150.842	NSW	26/09/1996	26/07/2006	1-hour	9.6
Toowoomba	-27.543	151.913	QLD	1/01/1997	26/07/2006	1-hour	9.4
Wagga Wagga	-35.158	147.457	NSW	1/01/1995	26/07/2006	1-hour	11.4
Walgett	-30.037	148.122	NSW	23/05/1997	26/07/2006	1-hour	9.1
Wandering	-32.672	116.671	WA	28/01/1999	5/11/2004	1-hour	5.6
Wangaratta	-36.421	146.306	VIC	20/02/1999	26/07/2006	1-hour	7.4
Warwick	-28.206	152.1	QLD	1/01/1995	26/07/2006	1-hour	7.8
West Wyalong*	-33.94	147.198	NSW	30/04/1999	26/07/2006	1-hour	7.2
Yanco	-34.622	146.433	NSW	5/08/1999	26/07/2006	1-hour	6.9
Young*	-34.251	148.246	NSW	1/01/1995	26/07/2006	1-hour	11.4
Yunta*	-32.572	139.564	SA	5/07/1998	26/07/2006	1-hour	7.6

* New sites that were not included in the previous RAP (2004).

4. Calculation methodology

4.1 Solar radiation

Solar radiation (SolRad in W/m^2) is not recorded at any of the Bureau of Meteorology AWS sites. The following equations were used to calculate solar radiation for each hour for each day based on the location of the sun throughout the day and year (Oke, 1987). The equation assumes no reduction in radiation due to cloud cover resulting in a conservative estimate of the HLI.

$$localHr = \frac{15\pi}{180}(12 - t)$$
$$declination = \frac{-23.5\pi}{180}\cos\left(\frac{2\pi(day + 10)}{365}\right)$$
$$elevation = \sin^{-1}\left(\sin(lat)\sin(declination) + \cos(lat)\cos(declination)\cos(localHr)\right)$$
$$SolRad = 1050\sin(elevation) - 65$$

Where:

t is the time of the day in hours
day is the Julian day of the year
lat is the latitude of the site.

4.2 Extrapolation of wind speed from 10 m to 2 m

The monitoring sites measure wind speeds at 10 m, therefore to represent winds at ground level the winds were corrected down to a height of 2 m. The winds were calculated as follows:

Between 6 am and 6 pm assume D class stability (neutral):

$$U_{2m} = U_{10m} \times (2/10)^{0.15}$$

Between 6 pm and 6 am assume F class stability (stable):

$$U_{2m} = U_{10m} \times (2/10)^{0.55}$$

where

U_{2m} is the wind speed at 2 m (m/s)
U_{10m} is the wind at 10 m (m/s)

4.3 HLI calculation

To calculate the HLI for each data record, the following equations were used:

$$BGT = 1.33*Temp - 2.65*\sqrt{Temp} + 3.21*\log(SolRad + 1) + 3.5$$
$$if\ \ BGT < 25$$
$$HLI = 1.3*BGT + 0.28*RelHum - WSpeed + 10.66$$
$$else$$
$$HLI = 1.55*BGT + 0.38*RelHum - 0.5*WSpeed + \exp(2.4 - WSpeed) + 8.62$$

where:

Wspeed (Wind speed) is measured in m/s.
Temp (Temperature) is measured in °C.
RelHum (Relative humidity) is expressed as a %.
SolRad (Solar radiation) is measured in W/m².
BGT (Black Globe Temperature) stated in ºC.

4.4 AHLU calculation

The AHLU was calculated using the following algorithm:

$$
\begin{aligned}
&if\ \ HLI < 77\\
&excess = HLI - 77\\
&else\ if\ \ HLI > upper\_threshold\\
&excess = HLI - upper\_threshold\\
&else\\
&excess = 0\\
\\
&if\ \ excess < 0\\
&excess = excess / 2 \qquad \text{// halve it for slower recovery rate}\\
\\
&excess = excess * time\_interval\\
&AHLU_{new} = AHLU_{old} + excess
\end{aligned}
$$

Where:

HLI is the Heat Load Index
AHLU is the Accumulated Heat Load Unit.
upper_threshold is the HLI value where AHLU starts to accumulate
time_interval is the interval between HLI estimates (1 hour)

5. Heat stress factors

5.1 AHLU

The AHLU is obtained by integrating or, in the case of discrete data, accumulating the product of HLI and time interval (in hours) between HLI estimates. The AHLU can be thought of as the level of heat stress existing in a system. A high HLI for a short time interval will have the same impact as a low HLI over a long time interval. Conversely, a high HLI for long periods of time will result in high (and detrimental) values of AHLU.

The Thermo-Neutral zone is defined as a range of HLI values wherein no heat stress is accumulated by cattle. The lower boundary of the Thermo-Neutral zone is set at a HLI value of 77 – recovery occurs when the HLI falls below this value. The upper boundary (upper HLI threshold) of the Thermo-Neutral zone depends on the genus, physical condition and the pen environment of the cattle in question.

Different genotypes react differently to heat load. For example, healthy Bos Taurus would exhibit the symptoms of heat stress at an earlier stage than a healthy Bos Indicus exposed to identical conditions. In other words, Bos Taurus will reach a given AHLU level more quickly than Bos Indicus. To incorporate this into the AHLU calculation and still maintain a consistent correspondence between AHLU and cattle heat stress, an upper HLI threshold below which the AHLU does not accumulate is obtained in terms of genotype, pen conditions and animal state.

Thus there are two HLI thresholds that must be considered when calculating the AHLU. An upper threshold determined by answering the questions presented in the RAP and a lower threshold set at 77. If the HLI value exceeds the upper threshold, the AHLU is incremented by the product of the interval between HLI values and the difference between the HLI and the upper threshold. If the HLI value is less than the lower threshold, the AHLU is decremented by one half of the product of the interval and the difference between the lower HLI threshold and the actual HLI value. The factor of one half is included to allow for the slower recovery rates.

Evidently, the upper HLI threshold can take a large number of values depending on the characteristics of the animal and its environment, resulting in a corresponding large number of AHLU values.

5.2 Heat stress risk and AHLU

A direct measure of heat stress is the panting score. This is obtained by measuring the breathing rates of cattle in the feedlot. The relationship between AHLU and panting score is summarised in Table 3.

Table 3: Heat stress risk with increasing AHLU values.

AHLU	Heat stress category	Cattle indications
0-20	Low risk	No stress or panting score 1
20-50	Medium risk	Panting score 1-2
50-100	High risk	Panting score 2-4
Over 100	Extreme risk	Panting score 4

5.3 Calculation of site statistics

The AHLU was calculated for each site for all upper HLI thresholds ranging from 77 to 110. For each upper HLI threshold the number of events of high or extreme risk were determined for two, three, four, five, six and seven days or more event duration. The statistics for each site are presented in the form of recurrence intervals for each event. For example, for a 10-year data set, if one extreme AHLU of 4-day duration event was found, this event was reported as having a recurrence interval of one every 10 years. Similarly, if an event was found to occur 10 times in a 10-year data set, its recurrence interval was reported as one event per year. When no event has been recorded the RAP will display less than 1 event for the period of the data set.

Monthly statistics were also calculated for each site. Events, which overlapped monthly boundaries, were included in both months.

6. Heat stress site comparisons and validation

The HLI and AHLU's calculated for each site were compared on a regional basis to examine any irregularities in the data sets. Due to the sensitivity of the HLI to high relative humidity there were a significant number of high HLI and AHLU events that were considered to be unrealistic. At a number of sites the relative humidity reached and stayed at 100% for more than a few days when no rainfall was recorded at the site. These events were edited out as they were considered erroneous and could result in an unrealistic heat stress event.

Each of the sites were checked by the following methods:

- Time-series of the HLI and various AHLU thresholds;
- Comparison of events and upper HLI thresholds generated for sites within a similar climatic region.
- Review of the frequency of heat stress events;
- Inspection of all high heat stress events to determine whether the event is real or due to an error in the data;
- Comparing sites on a per year heat stress risk basis.

A meeting was also held between Katestone Environmental, Des Reinhart and John Gaughan to review the high heat stress events for key sites. In this meeting it was agreed that a one-day event would not results in cattle heat stress and therefore the one-day events were removed from the RAP.

An analysis of the high HLI threshold for each site, which resulted in no extreme events of 2-day duration, was is used to identify any anomalies in the date. The contour presented in Figure 2 indicates the higher HLI thresholds for Queensland sites and central NSW. A comparison of the old and new RAP is also presented in Table 4. The maximum upper HLI threshold calculated in the old RAP was 95, therefore some sites are difficult to compare.

Figure 2: Contour of high HLI threshold for each site resulting in no extreme events of 2 day duration

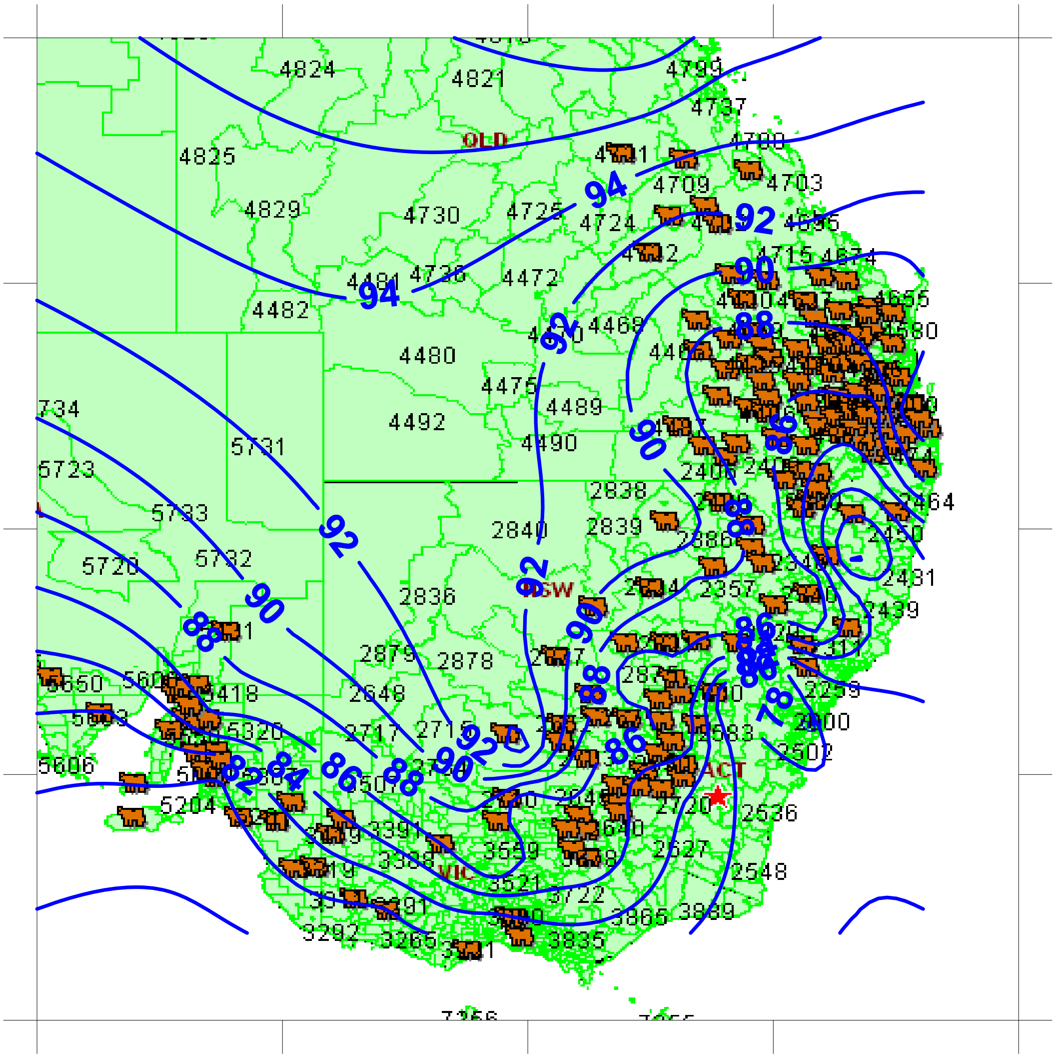


Table 4: Comparison of high HLI threshold values for old and new RAP.

Hourly AWS	New RAP			Old Rap		
Name	HLI threshold resulting in no extreme risk events			HLI threshold resulting in no extreme risk events		
	1 day	2 day	3 day	1 day	2 day	3 day
Albany	86	82	79	85	81	79
Albury	Site removed as not representative of area			93	91	88
Amberley	92	91	91	95+	95+	95+
Armidale	78	77	77	79	79	79
Ayr	100	100	99	New site		
Bendigo	88	88	84	New site		
Bridgetown	85	79	78	85	83	79
Bundaberg	90	89	89	New site		

Casino	90	89	89	90	90	89
Clare	86	86	84	87	86	82
Cleve	84	82	81	81	84	82
Cobar	91	91	91	New site		
Colac	Site removed due to insufficient data			79	79	79
Condobolin	85	84	83	85	85	83
Coonamble	89	88	88	89	88	88
Deniliquin	84	84	84	New site		
Dubbo	87	86	85	87	86	84
Emerald	94	92	89	95+	95+	95+
Geelong	85	80	77	80	79	79
Glen Innes	80	80	77	79	79	79
Goondiwindi	Site removed due to insufficient data			95	95	94
Griffith	89	88	88	New site		
Hay	104	95	95	95+	95+	95+
Inglewood	Site removed due to insufficient data			87	86	86
Hamilton	84	80	78	New site		
Katanning	84	84	80	86	87	83
Kingaroy	Site removed due to insufficient data			86	86	86
Kyabram	Site removed due to insufficient data			86	85	83
Mackay	95	95	95	New site		
Miles	Site removed due to insufficient data			89	89	88
Morawa	88	86	85	New site		
Moree	87	87	87	87	85	85
Mount Lofty	82	80	78	New site		
Mudgee	86	85	84	87	83	81
Naracoorte	83	81	81	83	80	81
Newdegate	86	86	83	86	85	83
Nullo Mountain	79	78	77	New site		
Oakey	86	86	85	86	86	85
Orange	80	77	77	79	79	79
Parkes	86	86	84	87	86	84
Rockhampton	94	93	93	New site		
Roma	88	87	87	95+	95+	95+
Scone	88	87	86	New site		
St George	89	88	87	93	90	83
Stanthorpe	86	84	82	91	90	89
St Lawrence	Site not representative of local area			95+	95+	95+
Tamworth	88	87	85	88	87	85
Toowoomba	85	84	83	85	85	84
Wagga Wagga	84	83	83	91	91	90
Walgett	91	91	90	90	90	89
Wandering	85	84	82	85	84	82
Wangaratta	86	86	84	New site		
Warwick	Site taken out due to insufficient data			94	94	93
West Wyalong	88	87	86	New site		
Yanco	86	86	86	86	86	86
Young	88	85	83	New site		
Yunta	90	89	86	New site		

7. Heat stress factors and mitigation reduction measures

A meeting was held at Wainui Feedlot, Dalby on 6 October with representatives from MLA, ALFA, University of Queensland and Katestone Environmental with the purpose of revising the factors affecting the HLI threshold at which heat begins to accumulate. Changes to the previous work included the following:

- Remove body condition score and replace with days on feed.
- Modification to the genotype classifications for Bos Indicus cross breads.
- Setting of an upper limit of genotype plus 10 for any mitigation measures or management factors

The final parameters and their change to the upper HLI threshold are presented in Table 5.

Table 5: List of parameters and their effect on the HLI threshold. Positive numbers increase the HLI threshold (mitigation measures) while negative numbers decrease the HLI threshold. Default values highlighted

Factors	Parameters	Upper HLI Adjustment
Animal Factors	**Bos Taurus genotype**	0
	European genotype	+3
	Wagyu genotype	+4
	100% Bos Indicus genotype	+10
	75% Bos Indicus genotype	+8
	50% Bos Indicus genotype	+7
	25% Bos Indicus genotype	+4
	Black coat colour	0
	Red coat colour	+1
	White coat colour	+3
	Less than 80 days on feed	+2
	80-130 days on feed	0
	Greater than 130 days on feed	-3
	Healthy	0
	Sick/Recovering/Unacclimatised	-5
Management Factors	Additional 1.5-2 m^2/head	+3
	Additional 2-3 m^2/head	+5
	Additional 3.5 m^2/head	+7
	Trough water temperature = 15 - 20°C	+1
	Trough water temperature = 20 - 30°C	**0**
	Trough water temperature = 30 - 35°C	-1
	Trough water temperature = above 35°C	-2
	Manure management feedlot class = 1	**0**
	Manure management feedlot class = 2	-4
	Manure management feedlot class = 3	-8
	Manure management feedlot class = 4	-8

Mitigation Strategies	Installation of additional water troughs [1]	1
	Implementing of heat load feeding strategy	2
	Strategic clearing of high manure deposition areas	2

Notes: 1 Only used if no shade is provided

8. Delivery of RAP

The RAP is available in two formats. The program supplied with the previous version of the RAP was upgraded to include the new factors as listed in Table 5 and other minor modifications. To ensure that future modifications are easily disseminated to the feedlot operators a new version of the RAP was made available on the web (http://www.katestone.com.au/rap). This also includes a HLI calculator and AHLU calculator. The current structure of the Katestone/MLA heat load web site is under review and will be modified to include the RAP, both web based and downloadable HLI and AHLU calculator spreadsheets and the heat load forecasting.

Screen grabs of the RAP and HLI calculator are presented in Figure 3, Figure 4, Figure 5 and Figure 6.

9. Conclusions and recommendations

The updated version of the RAP has been modified to incorporate new research into the effects of heat on different breeds of cattle and updates of the meteorological database used to generate the HLI and risk statistics. Considerable time was spent validating the risk levels predicted by the RAP to ensure consistency across sites. A number of the heat stress events included in the previous RAP were edited, as the HLI was unrealistically high, which was typically due to errors in relative humidity measurements. Due to the high scrutiny of the meteorological data a number of sites that were previously included in the RAP were removed.

The RAP is now available on the web (http://www.katestone.com.au/rap), along with calculators for the HLI and AHLU. Putting the RAP on the web will allow better management of future updates.

To ensure the RAP is representative of the future climate the period of data analysed and included in the RAP has been restricted to the past 10 years (1995 – 2006). The impacts of climate change on the intensity and frequency of heat stress events are not fully understood, as the future increase in temperature will increase the HLI but the decrease in rainfall may result in a reduction in relative humidity, which would reduce the HLI.

In reviewing the large volume of data for this project it was noted that the HLI was very sensitive to high relative humidity, particularly for lower temperatures. In future reviews of the HLI we recommend more detailed analysis of the impact of very high relative humidity on heat stress.

Figure 3: Web RAP – input page

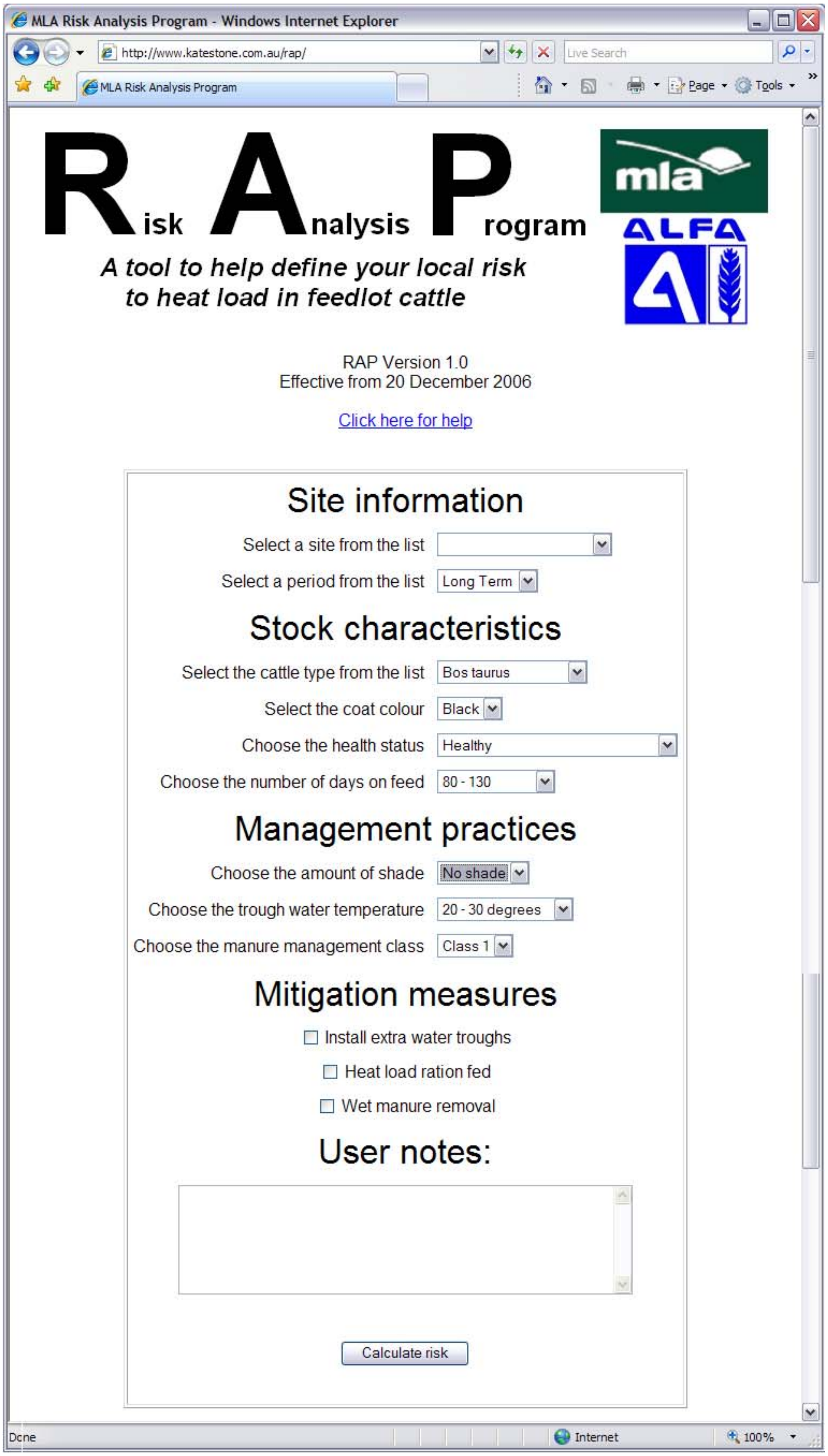
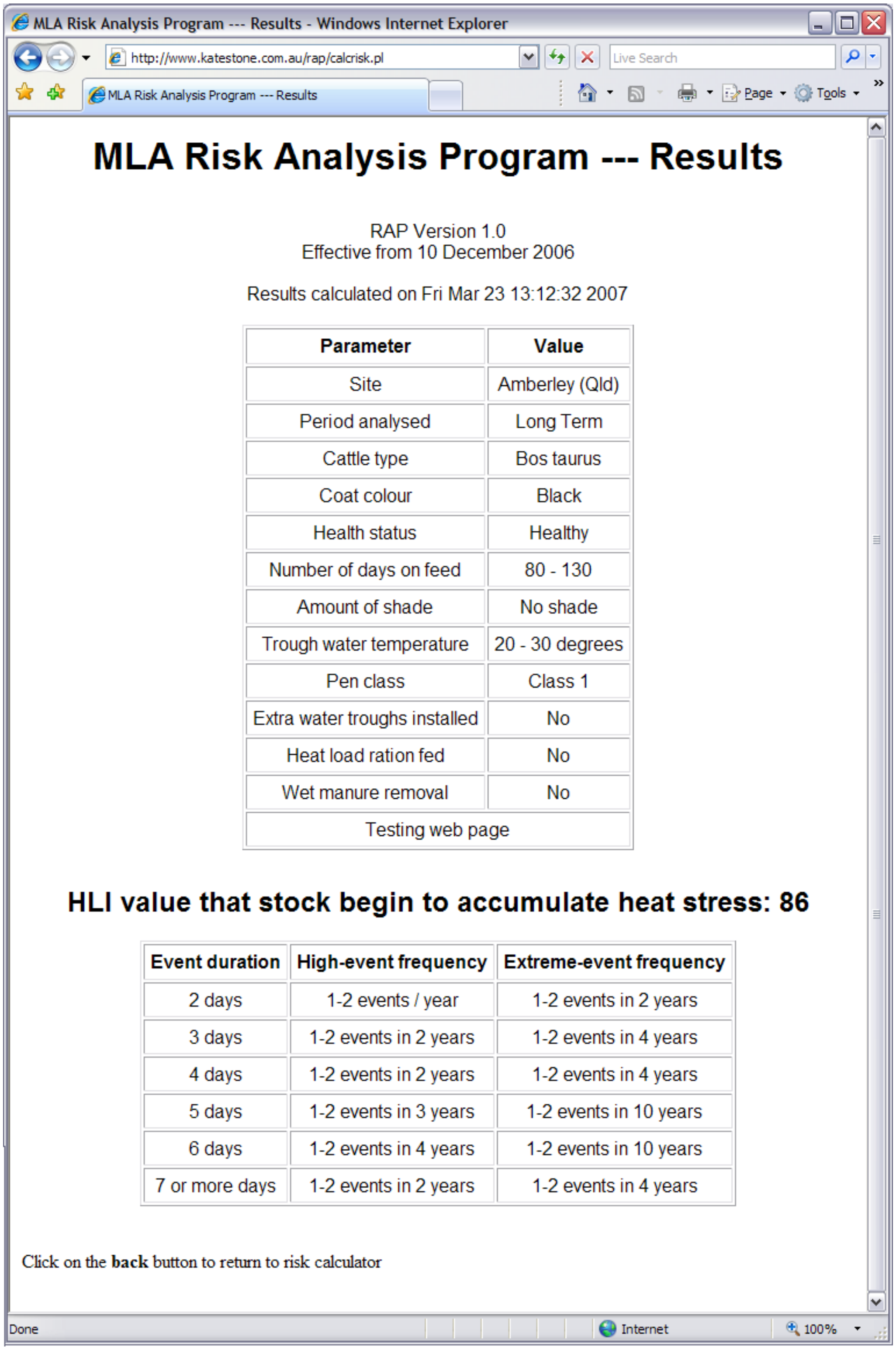


Figure 4: Web RAP – results page



MLA Risk Analysis Program --- Results

RAP Version 1.0
Effective from 10 December 2006

Results calculated on Fri Mar 23 13:12:32 2007

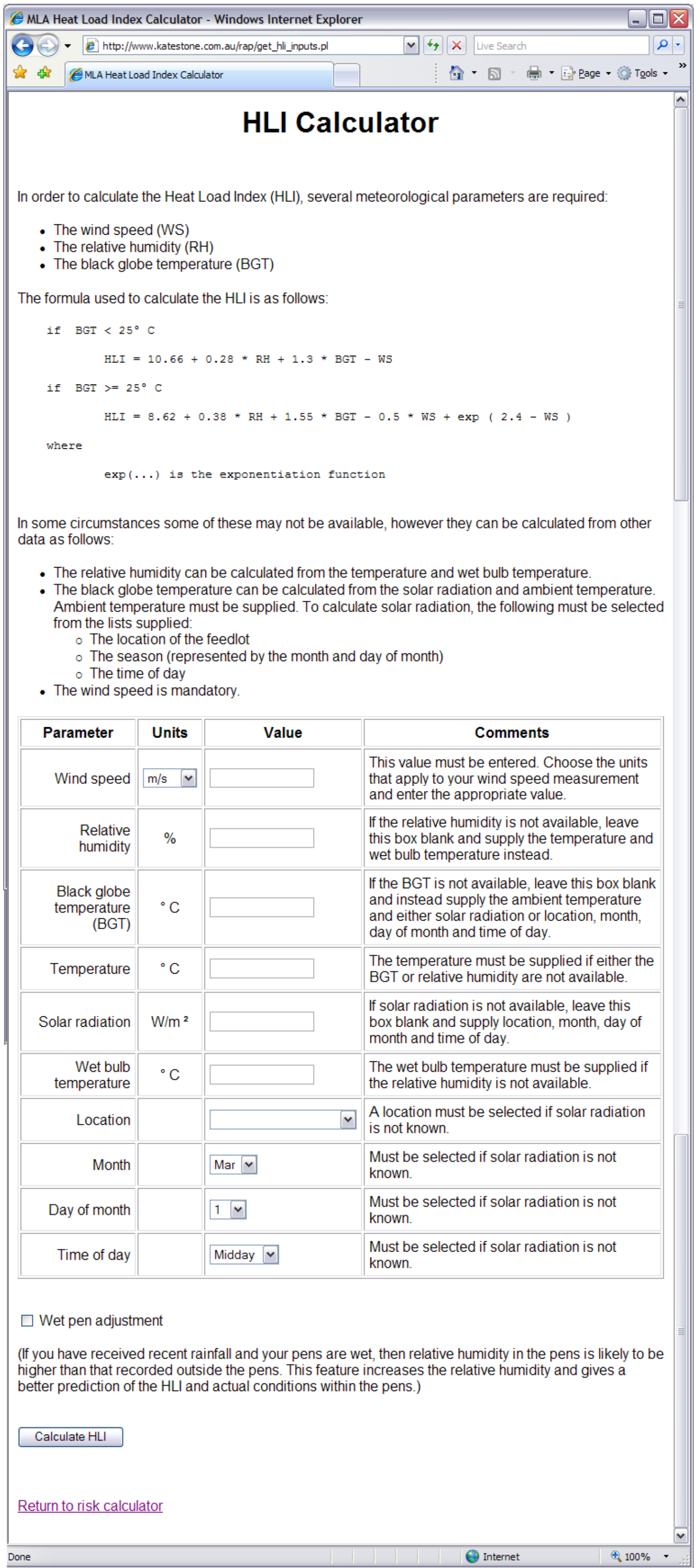
Parameter	Value
Site	Amberley (Qld)
Period analysed	Long Term
Cattle type	Bos taurus
Coat colour	Black
Health status	Healthy
Number of days on feed	80 - 130
Amount of shade	No shade
Trough water temperature	20 - 30 degrees
Pen class	Class 1
Extra water troughs installed	No
Heat load ration fed	No
Wet manure removal	No
Testing web page	

HLI value that stock begin to accumulate heat stress: 86

Event duration	High-event frequency	Extreme-event frequency
2 days	1-2 events / year	1-2 events in 2 years
3 days	1-2 events in 2 years	1-2 events in 4 years
4 days	1-2 events in 2 years	1-2 events in 4 years
5 days	1-2 events in 3 years	1-2 events in 10 years
6 days	1-2 events in 4 years	1-2 events in 10 years
7 or more days	1-2 events in 2 years	1-2 events in 4 years

Click on the **back** button to return to risk calculator

Figure 5: Web HLI calculator


MLA Heat Load Index Calculator - Windows Internet Explorer

http://www.katestone.com.au/rap/get_hli_inputs.pl

HLI Calculator

In order to calculate the Heat Load Index (HLI), several meteorological parameters are required:

- The wind speed (WS)
- The relative humidity (RH)
- The black globe temperature (BGT)

The formula used to calculate the HLI is as follows:

```
if  BGT < 25° C

        HLI = 10.66 + 0.28 * RH + 1.3 * BGT - WS

if  BGT >= 25° C

        HLI = 8.62 + 0.38 * RH + 1.55 * BGT - 0.5 * WS + exp ( 2.4 - WS )

where

        exp(...) is the exponentiation function
```

In some circumstances some of these may not be available, however they can be calculated from other data as follows:

- The relative humidity can be calculated from the temperature and wet bulb temperature.
- The black globe temperature can be calculated from the solar radiation and ambient temperature. Ambient temperature must be supplied. To calculate solar radiation, the following must be selected from the lists supplied:
  - The location of the feedlot
  - The season (represented by the month and day of month)
  - The time of day
- The wind speed is mandatory.

Parameter	Units	Value	Comments
Wind speed	m/s		This value must be entered. Choose the units that apply to your wind speed measurement and enter the appropriate value.
Relative humidity	%		If the relative humidity is not available, leave this box blank and supply the temperature and wet bulb temperature instead.
Black globe temperature (BGT)	°C		If the BGT is not available, leave this box blank and instead supply the ambient temperature and either solar radiation or location, month, day of month and time of day.
Temperature	°C		The temperature must be supplied if either the BGT or relative humidity are not available.
Solar radiation	W/m²		If solar radiation is not available, leave this box blank and supply location, month, day of month and time of day.
Wet bulb temperature	°C		The wet bulb temperature must be supplied if the relative humidity is not available.
Location			A location must be selected if solar radiation is not known.
Month		Mar	Must be selected if solar radiation is not known.
Day of month		1	Must be selected if solar radiation is not known.
Time of day		Midday	Must be selected if solar radiation is not known.

☐ Wet pen adjustment

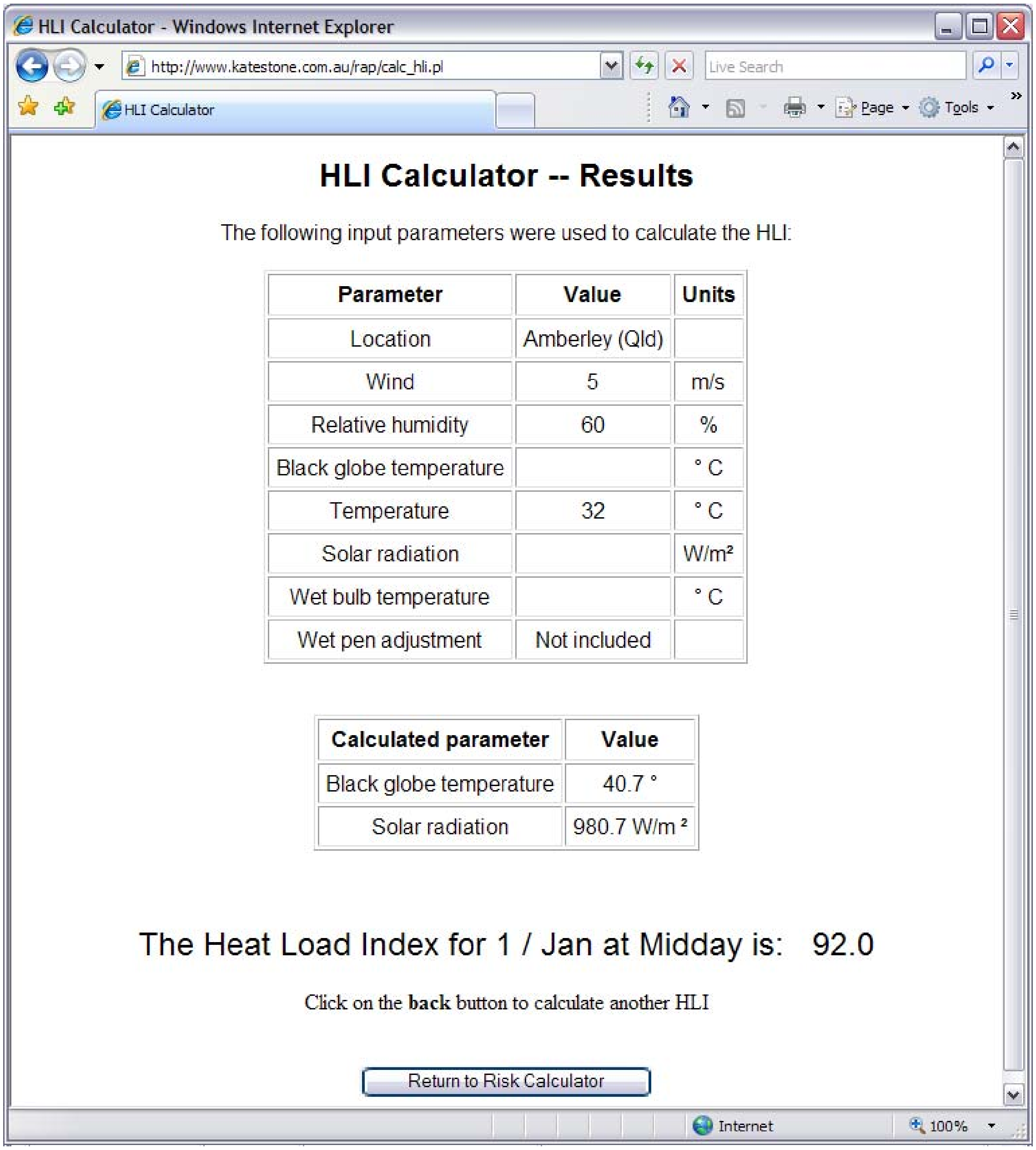
(If you have received recent rainfall and your pens are wet, then relative humidity in the pens is likely to be higher than that recorded outside the pens. This feature increases the relative humidity and gives a better prediction of the HLI and actual conditions within the pens.)

Calculate HLI

Return to risk calculator

Done Internet 100%

Figure 6: Web HLI calculator - results



HLI Calculator - Windows Internet Explorer

http://www.katestone.com.au/rap/calc_hli.pl

HLI Calculator -- Results

The following input parameters were used to calculate the HLI:

Parameter	Value	Units
Location	Amberley (Qld)	
Wind	5	m/s
Relative humidity	60	%
Black globe temperature		° C
Temperature	32	° C
Solar radiation		W/m²
Wet bulb temperature		° C
Wet pen adjustment	Not included	

Calculated parameter	Value
Black globe temperature	40.7 °
Solar radiation	980.7 W/m ²

The Heat Load Index for 1 / Jan at Midday is: 92.0

Click on the **back** button to calculate another HLI

Return to Risk Calculator

10. References

CSIRO (2001), www.cmar.csiro.au/e-print/open/projections2001.pdf

CSIRO (2001)b, “Climate change impacts for Australia”, www.marine.csiro.au/iawg/impacts2001.pdf

Howden S, McKeon G and Reyenga P (1999), Global change impacts on Australian rangelands, Working Paper series 99/09, Report to the Australian Greenhouse Office, CSIRO Wildlife and Ecology.

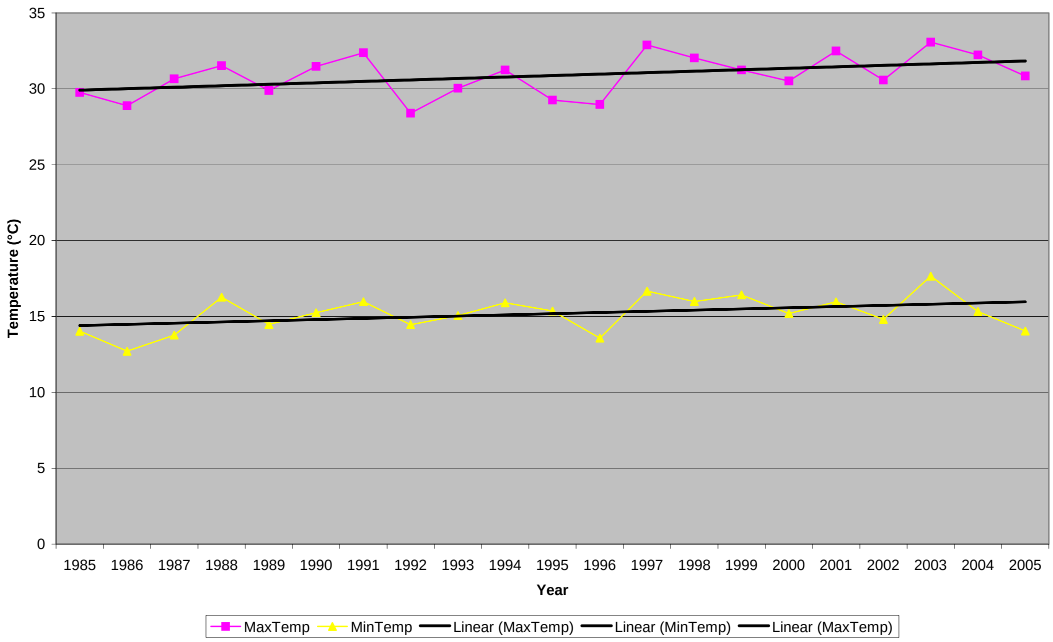
Bouma W, Pearman G and Manning M (1996), Greenhouse coping with climate change, Specifically Whetton P, Mullan A, Barrie Pittock A, Climate-Change scenarios for Australia and New Zealand.

IPCC (2001), Climate change 2001: the scientific basis.

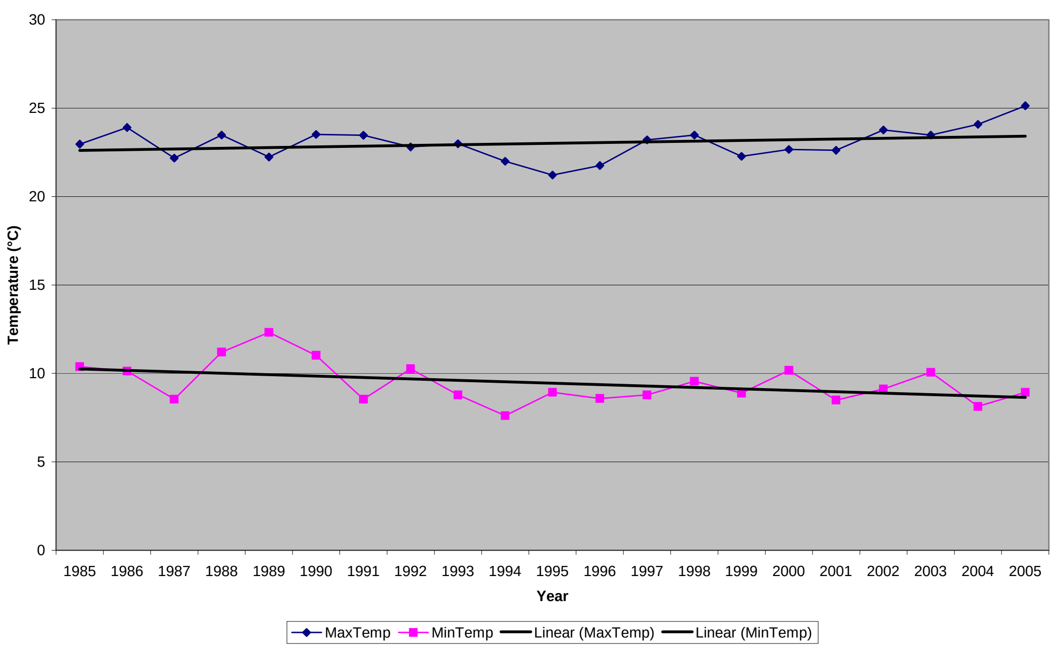
Appendix 1: Seasonal plots of the average daily maxima and minima temperatures for Wagga Wagga, Amberley and Albury.

MLA climate change analysis – Wagga Wagga

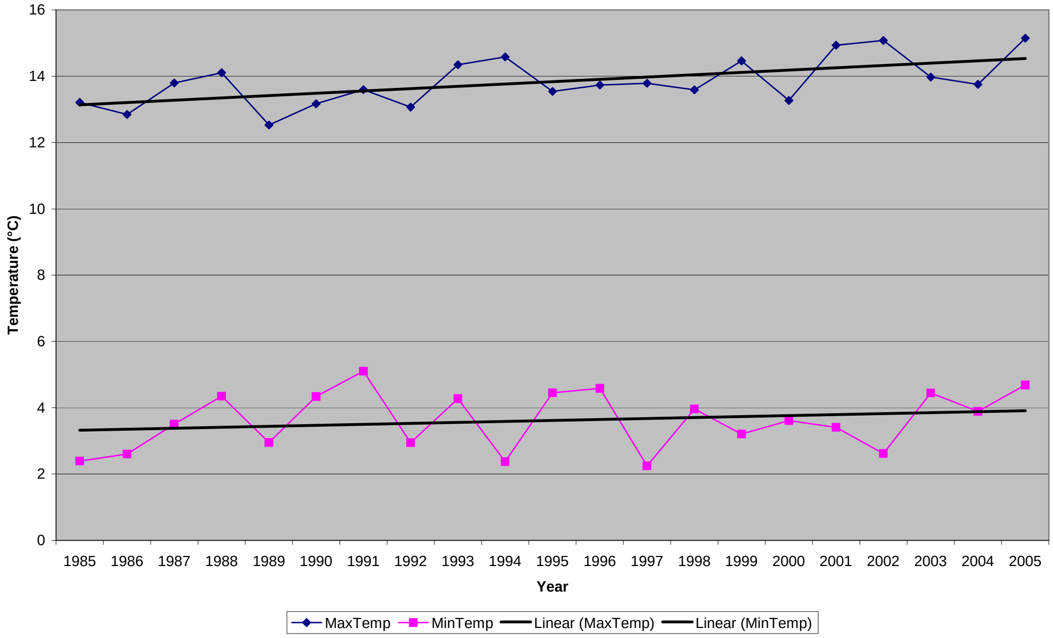
Summer



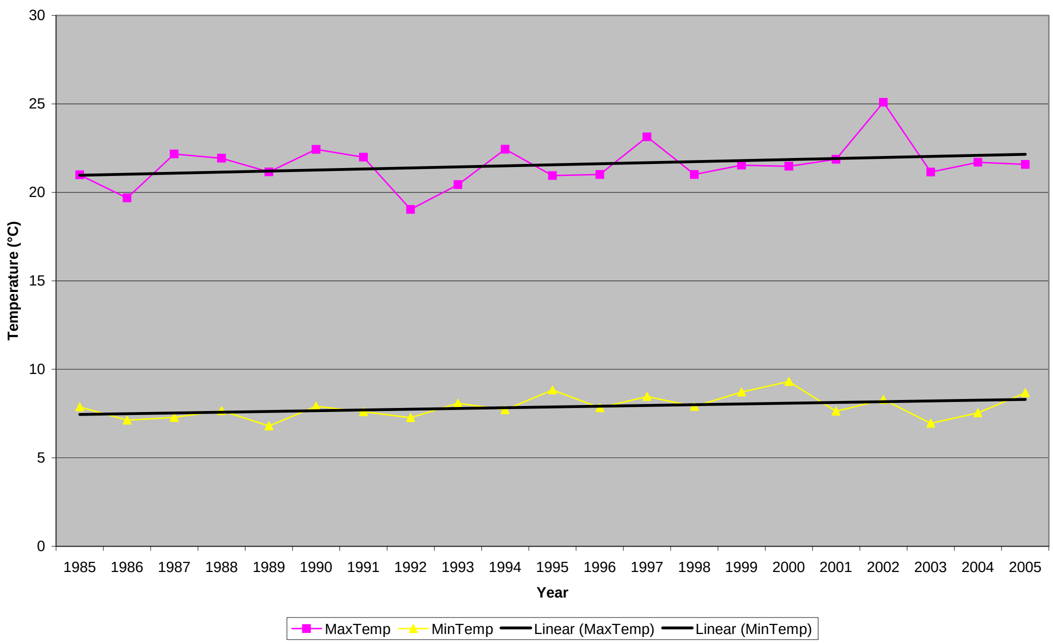
Autumn



Winter

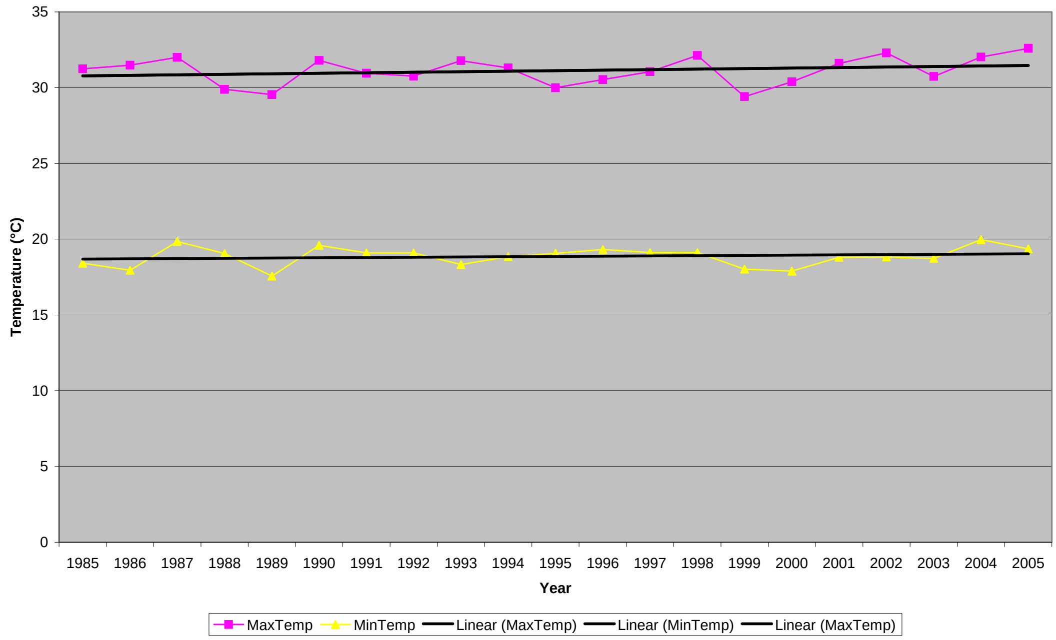


Spring

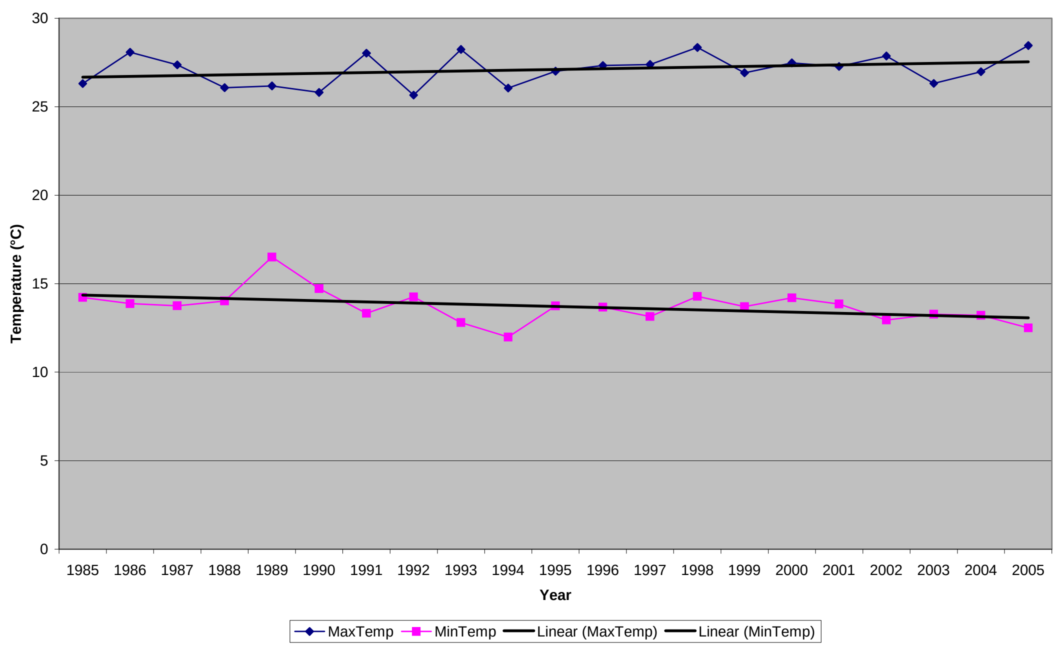


MLA climate change analysis – Amberley

Summer



Autumn



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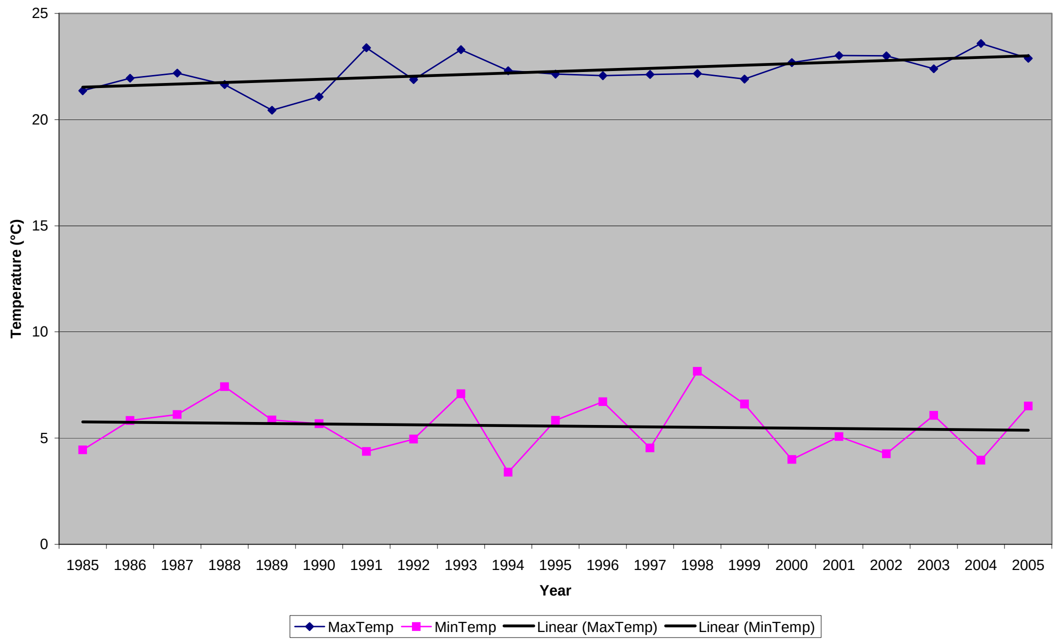
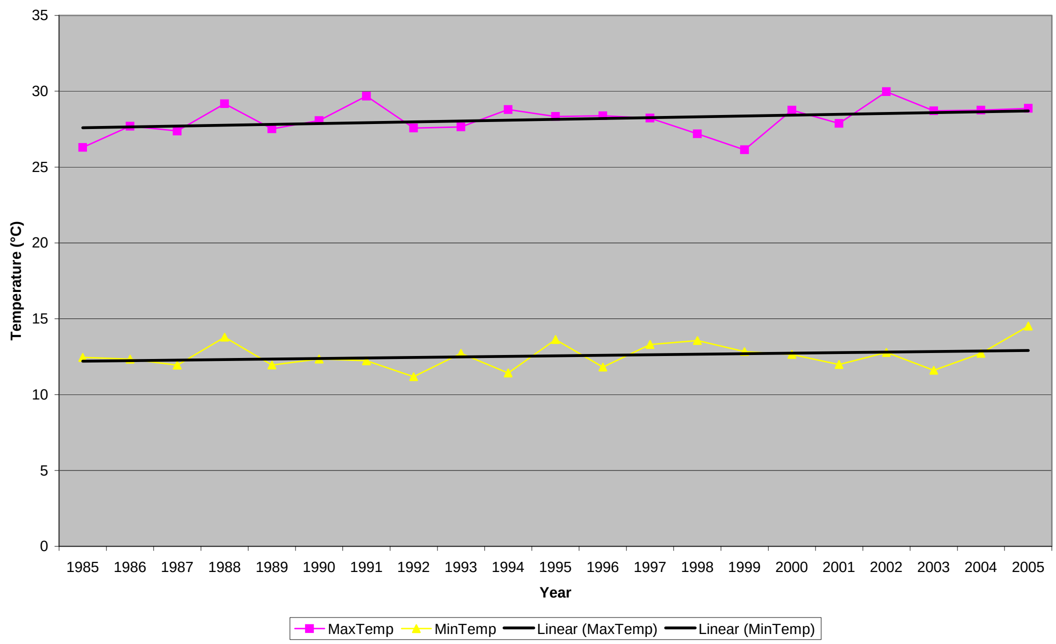
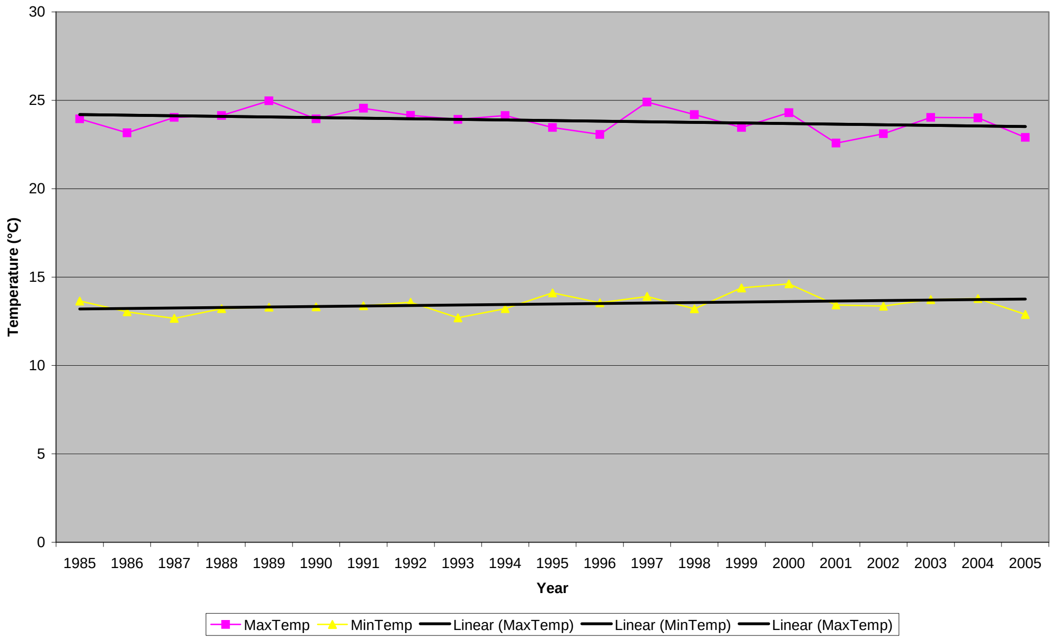


Spring

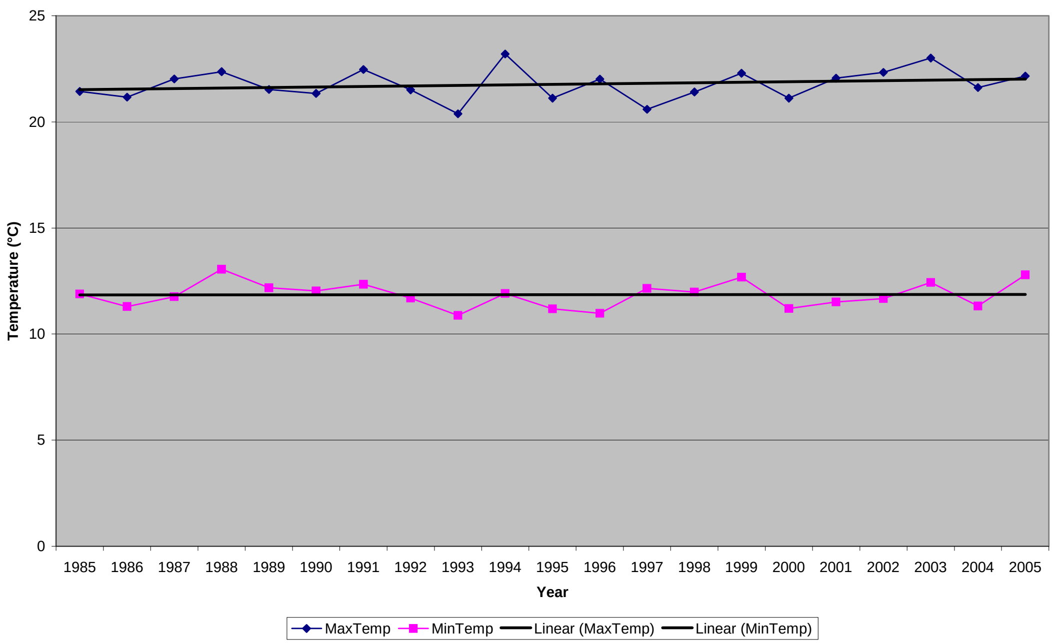


MLA climate change analysis – Albany

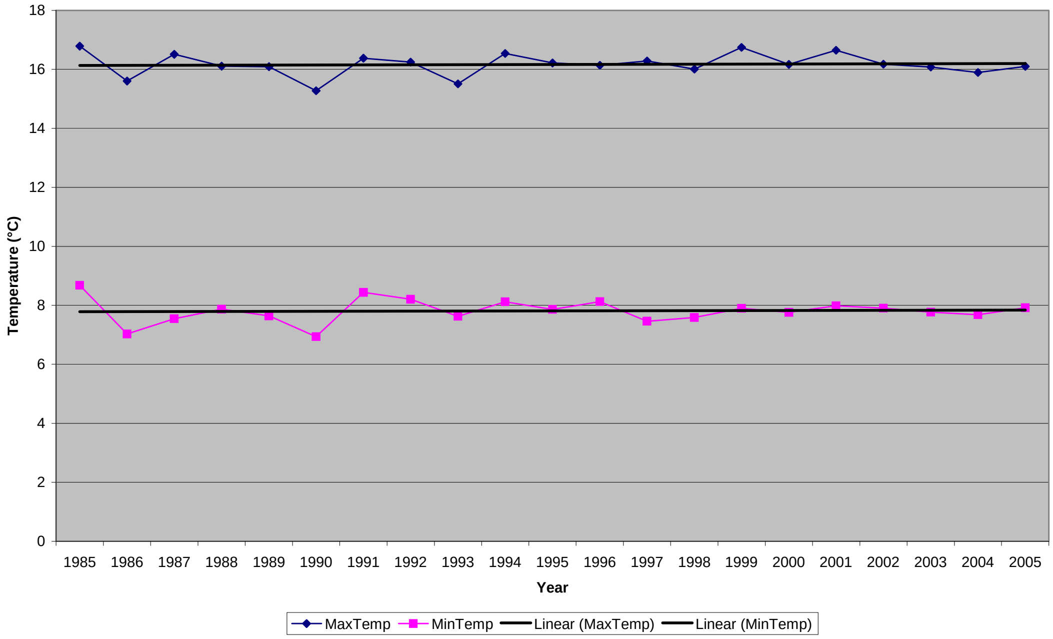
Summer



Autumn



Winter



Spring