MEAT & LIVESTOCK AUSTRALIA

on farm

Cattle heat load forecasting service for 2004/2005 summer

Project number FLOT. 329
Report prepared for MLA by:

Katestone Environmental
PO Box 2184, Toowong QLD 4066

Meat & Livestock Australia Limited
Locked Bag 991
North Sydney NSW 2059

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Feedlots

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ABSTRACT

A weather forecasting system was developed to assist in warning feedlot operators of impending adverse weather conditions that could lead to excessive heat loads (and potential mortality) for feedlot cattle. This forecasting system covered several locations in the proximity of feedlots where Bureau of Meteorology automatic weather stations (AWS) are located.

The forecasts were made over a four month period in summer (2004-05) at 16 sites throughout Queensland, New South Wales, South Australia, Western Australia and Victoria. Forecasts were made of wind speed, temperature and dew point, these being the input parameters necessary to calculate the Heat Load Index (HLI).

Forecasts for all 16 sites were posted daily onto a website (www.katestone.com.au/mla) for easy access to all feedlot operators.

In the present study, the algorithm for calculating the HLI was revised to include the wind speed and also a new parameter, the Accumulated Heat Load Index (AHLU), was introduced. There was good agreement between the forecast and observed temperature and dew point from which the relative humidity was calculated. Solar radiation was calculated analytically using the date, time of day and latitude of the site. The wind speed forecasting performance was relatively poor, resulting in discrepancies in the HLI and AHLU forecasts. The major source of disagreement stems from two causes: the poor performance in forecasting wind speed and the strong dependence of HLI on wind speed.

In terms of forecasting the heat stress category, it should be noted that the categories are broad – the low risk category ranges from 0 to 20 AHLUs, the higher risk categories extend over 30 and 50 AHLUs. Therefore, although agreement between the forecast and observed AHLU values might be poor, these would fall into the same heat stress category, giving better performance in predicting the category in contrast to forecasting individual AHLU values. It is more important to predict the heat stress category well than the actual AHLU, therefore the forecasting performance is reasonably good.

EXECUTIVE SUMMARY

Introduction

One of the issues that needs to be addressed in managing feedlots is the possibility of cattle deaths due to heat stress brought on by adverse weather conditions. One tool of managing heat stress is to forecast stress inducing conditions for a prescribed future period. In the summer of 2001-02, Katestone Environmental developed a forecasting system for MLA to predict a cattle heat stress index out to 6 days ahead for four sites in Queensland and New South Wales. Meteorological data were obtained on a daily basis from the on-site meteorological stations and the nearest Bureau of Meteorology automatic weather station (AWS). From these data, an indicator of heat stress. The Temperature Humidity Index (THI, an indicator of heat stress) was calculated from these data and made available to feedlot operators.

The forecasting study was expanded over the summer of 2002-03 to incorporate a Heat Load Index (HLI) developed specifically for feedlot cattle and to extend the coverage to 14 sites across eastern Australia. The service was expanded for the 2003-04 summer period with the addition of Katanning (Western Australia) and again in 2004-05 to include Charleton in Victoria and also to incorporate a revised HLI algorithm and the Accumulated Heat Load Unit (AHLU). The present study includes the following 16 sites:

- Queensland – Amberley, Emerald, Miles, Oakey, Roma, Warwick;
- New South Wales – Albury, Armidale, Griffith, Hay, Moree, Tamworth, Yanco;
- South Australia – Clare;
- Western Australia – Katanning; and
- Victoria – Charleton.

Key issues

The key issues in implementing a viable feedlot weather forecasting system include:

(a) Identification of primary and derived meteorological parameters that indicate excessive heat load in cattle and cattle storage mechanisms.

(b) Selection of methodology for predicting primary and derived parameters at AWS locations for a suitable time horizon.

(c) Development of a forecasting software system for predicting feedlot conditions.

(d) Making the forecasting results available to all feedlot operators on a daily basis.

At the outset, the following constraints were identified:

- Bureau of Meteorology AWS sites are not generally in close proximity to feedlots and this limits the utility of forecasts made from these sites. Most AWSs are situated near significant populations or industrial regions and as such only 16 sites were identified to be in close proximity to feedlot operations.

- The Bureau of Meteorology's model data (LAPS and GASP), necessary to conduct a forecast, is only stored by the Bureau of Meteorology when requested. Therefore the models created for the recently added sites (viz. Katanning and Charleton) were based on a small amount of historical LAPS/GASP data which can affect model performance.

- It was found that the most effective technology for making the forecasts available to feedlot operators was through the World Wide Web. The advantages are that the data can be presented in a way which is easily interpreted and is readily accessible by all feedlots.

Selected methodology

The following methodology was adopted following discussions between MLA and Katestone Environmental on the most viable options:

- Utilise fully the information from the nearest AWS maintained by the BoM.

- Calculate the key parameters at a fine time resolution out to 6 days ahead.

- Forecasts transferred daily to a web site.

- Software system to include automatic model retraining as more data become available.

The forecasts were based on the models generated during the previous study conducted by Katestone Environmental for MLA. See Appendix A for a description of the models.

Forecast performance

There was good agreement between the forecast temperature and dew point and the observed quantities. The wind speed forecasting performance was relatively poor, resulting in discrepancies in the HLI and AHLU forecasts.

In terms of forecasting the heat stress category, it should be noted that the categories are broad – the low risk category ranges from 0 to 20 AHLUs, the higher risk categories extend over 30 and 50 AHLUs. Therefore, although agreement between the forecast and observed AHLU values might be poor, these would fall into the same heat stress category, giving better performance in predicting the category in contrast to forecasting individual AHLU values.

Recommendations

If a future forecasting system is to include more sites, we would recommend ample warning of the sites of interest so we can request that the Bureau of Meteorology store the LAPS/GASP information for these regions. Having a larger database of information from which to conduct the forecasts would improve forecast performance in the initial months.

As heat stress management in cattle is an ongoing area of research, future projects should include up to date methods for calculating heat stress parameters on cattle and reporting these on a regular basis.

Reviewing the methodology for forecasting the wind speed should be given high priority as this was the major cause for the poor forecasting performance of half hourly HLI and AHLU parameters.

MAIN RESEARCH REPORT

Introduction

One of the issues facing feedlot managers is the possibility of cattle death in feedlots due to heat stress caused by adverse weather conditions. One tool in the overall management strategy is the ability to forecast stress inducing conditions for a prescribed future period. In the summer of 2001-02, Katestone Environmental undertook a feasibility study for MLA (FLOT.313) for forecasting excessive heat load in cattle. This forecasting system utilised data from four feedlots that operated on-site meteorological stations and was based on the calculation of the Temperature Humidity Index (THI), previously developed as an indicator of human comfort, derived from available forecast meteorological variables (temperature and dewpoint). Forecasts were conducted for on-site meteorological stations and for the nearest Bureau of Meteorology AWS. These forecasts were then compared with observations and it was confirmed that suitable forecasts could be generated from the AWS stations for the feedlot sites.

Recent studies on cattle heat stress (Gaughan et al., 2002) indicate that the HLI was a better indicator of cattle heat stress than the originally used THI. These studies also found that the number of hours that the HLI was above a threshold (89) was also a good indicator of accumulated heat load in cattle. The studies also found that if the HLI fell below 79 for a number of hours then the cattle would be able to recover somewhat from the heat stress.

Further studies (see MLA report FLOT.327) have indicated that the Accumulated Heat Load Unit (AHLU), a parameter obtained by accumulating the number of hours the HLI exceeds a certain threshold, is indicative of the heat stress in feedlot cattle. Also, it was found that the threshold depended on genus, environmental factors (wind speed, temperature etc) and pen factors (availability of shade, cooled drinking water etc).

This forecasting system has been expanded each summer to now include sixteen sites around Australia with forecasts being conducted every day over the summer period.

The study included the following sites:

- Queensland – Amberley, Emerald, Miles, Oakey, Roma, Warwick;
- New South Wales – Albury, Armidale, Griffith, Hay, Moree, Tamworth, Yanco;
- South Australia – Clare;
- Western Australia – Katanning; and
- Victoria –Charleton.

Study definition and objectives

The MLA requested a forecasting system to assist in identifying potential cattle heat stress events. The objectives of the study were to:

- Provide forecasts out to 6 days ahead for predicted maximum and minimum HLI, AHLU for various upper HLI thresholds and forecast rainfall. These forecasts were necessary for the summer period of 2004-05.
- Allow the forecasts to be accessible on a daily basis by each of the feedlot operators.
- Retrain the models regularly to improve the forecasts.

- Examine the accuracy of the forecasts.

Short-term forecasting of excessive heat load

Key forecasting parameters

Short-term forecasting of dry bulb temperature, dewpoint temperature and wind speed are performed on a routine basis by the Bureau of Meteorology. These are the parameters from which many heat comfort indices can be derived. It is also highly desirable to include rainfall and solar radiation parameters in any feedlot forecasting scheme but there is currently less skill in producing such forecasts.

Regional rainfall forecasts are available from the Bureau of Meteorology which have been included in the daily forecasts. Solar radiation was calculated analytically using the date, time of day and latitude of the site. The solar radiation value does not account for cloud cover and therefore will overestimate solar radiation for cloudy days. The dependence of the HLI on radiation used here is relatively minor and as such the resulting overestimation was not considered significant.

The above variables were used to calculate the HLI and AHLU for each site on a half-hourly basis.

Forecasting methodologies for fine spatial resolution

Most available forecast models give a regional forecast for areas up to usually 25 x 25 km. The forecasting system adopted for this project gives a forecast for the location of interest. This can be more beneficial in incorporating local influences on the meteorology such as terrain.

The forecast models for each site for the meteorological variables were produced using the same methodology as previous forecasting detailed in “FLOT. 313 – Development and trial operation of a weather forecasting service for excessive heat load events for the Australian feedlot industry”. In these models, both the wind speed and wind direction are forecast for all sites except Griffith and Hay. For these sites it was necessary to model wind speed alone (as a scalar quantity) due to the large spatial separation between the feedlot and the upper-level input forecast region.

Bureau of Meteorology services

LAPS and GASP data were provided by the Bureau of Meteorology for each of the forecasting sites along with the AWS data on a daily basis. Details on this information can be found in the previous forecasting report (Katestone Scientific, 2002). The LAPS and GASP, along with the AWS data, were downloaded, on a daily basis from a web site specially arranged by the Bureau of Meteorology.

Parameters for characterising Heat Stress

Three parameters for characterising heat stress in feedlot cattle are the HLI, the AHLU and the panting score. The HLI and AHLU are indirect measures of heat stress, being derived from the prevailing meteorological conditions. The panting score is a direct measure, being derived from the breathing rate of cattle.

Heat Load Index (HLI)

The HLI is obtained from the half-hourly average meteorological parameters. These include wind speed, relative humidity and, through an intermediate parameter – the Black Globe Temperature (BGT) - temperature and solar radiation.

The HLI can be thought of as a rate of heat input into a system. Consequently, even though a high HLI value may be highly detrimental, it will have little effect if it is of short duration. A more sensible measure of heat stress is obtained by integrating the HLI to obtain the AHLU, which will be discussed in the following section.

Finally, if any calculation yielded a HLI value less than 50, this value was set to 50.

Accumulated Heat Load Unit (AHLU)

The AHLU is obtained by integrating or, in the case of discrete data, accumulating the product of HLI and interval (in hours) between HLI estimates. The AHLU can be thought of as the level of heat stress existing in a system. Obviously, a small HLI value for a period of time will result in low AHLU values as will a high HLI value for a short duration. 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.

Cattle react differently to HLI. For example, an unhealthy Bos Taurus would exhibit the symptoms of heat stress at an earlier stage than would 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. For discussion and details on how this upper threshold is calculated, the reader is referred to “FLOT. 327 – Development of a Heat Load Risk Assessment Process for the Australian feedlot industry”.

Thus there are two HLI thresholds which must be considered when calculating the AHLU. An upper threshold determined from the report cited above 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.

For example, suppose that the current AHLU value is 42 and the upper HLI threshold for a particular cattle type is 90. If the observed HLI were 94, then the excess would be +2 ((94–90)*0.5; the 0.5 being the half hour interval between observations) and this excess would be added to the current AHLU value giving a new AHLU value of 44. If, instead, the observed HLI value were 65, the nominal excess would be –6 ((65–77)*0.5; 77 being the lower threshold, 0.5 being the half hour interval between observations). Since the excess is negative, it is halved as the recovery rate is slower, thus final excess is now –3, giving a new AHLU value of 39. For HLI values between 77 and 90, the Thermo-Neutral zone, the excess would be zero.

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. To avoid the situation where excessive amounts of data are generated and analysed, it was decided to determine AHLU values for discrete upper HLI threshold values of 80, 83, 86, 89, 92 and 95.

Panting Score

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 the following table:

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

Relative Humidity Calculation

The relative humidity used in the calculation of HLI was calculated from the temperature (Temp in ºC) and dew point temperature (DewPt in ºC) using the following equation:

$$RelHum = 100 * \left(\frac{1.8*DewPt - 0.18*Temp + 201.8}{1.62*Temp + 201.8} \right)^{8}$$

Equation 1. Relative humidity calculated from temperature and dew point

Solar Radiation Calculation

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.

$$localHr = \frac{15\pi}{180}(12 - t)$$

$$declination = \frac{-23.5\pi}{180}\cos\left(\frac{2\pi(day + 10)}{365}\right)$$

$$elevation = \sin^{-1}\left(\sin(lat)\sin(declination) + \cos(lat)\cos(declination)\cos(localHr)\right)$$

$$SolRad = 1050\sin(elevation) - 65$$

Equation 2. Solar radiation equation

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.

Heat Load Index Calculation

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

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

Equation 3. Heat Load Index equations

where

WSpeed is measured in m/s.
Temp is measured in °C.
RelHum is measured in %.
SolRad is measured in W/m²
BGT is known as the Black Globe Temperature (ºC).

Accumulated Heat load Unit Calculation

The AHLU was calculated using the following algorithm:

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

Equation 4. Algorithm for accumulating AHLU

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 (0.5 hours)

Service delivery mechanisms

For this project, forecasts were automatically generated every morning (09:00 hrs), checked by Katestone Environmental staff and transferred to the web site www.katestone.com.au/mla.

Overall methodology

The prototype system was based on the models developed in our previous forecasting system developed for the MLA. It consists of the following steps:

(a) Obtain upper-level forecast data from numerical weather prediction models via a special web site maintained by the Bureau of Meteorology.

(b) Collect concurrent information from an automatic weather station close to the site of interest.

(c) Once a sufficient training set of information is collected, use proprietary Katestone software to develop statistical models that relate the surface measurement to a subset of the upper-level variables.

(d) Use these models and the most recent data to provide the necessary forecasts.

Accuracy of forecasting system

Statistical measures for forecast accuracy

Three coefficients were used to determine the performance of the HLI forecasting system: the Pearson Correlation Coefficient, Index Of Agreement (IOA) and the Root Mean Square Error (RMSE).

The Pearson Correlation Coefficient is a measure of the strength of the linear relationship between the predicted and observed measurements (defined in Equation 5). The closer this value is to unity the stronger the relationship. The Index Of Agreement (IOA) is defined in Equation 7 and gives an index from 0-1 (1 representing strong agreement). The Root Mean Square Error (RMSE) defined in Equation 6 is an indication of the absolute error. The smaller the RMSE (i.e. the closer the value is to zero) the better the forecast. Note that the RMSE does not indicate whether the forecasts are predominantly higher or lower than the observed values – ie whether the method over or under predicts – it only reports on the difference between the observed and predicted values.

The equations for calculating the coefficients are:

$$r = \frac{N\left(\sum_{i=1}^{N} O_i P_i\right) - \left(\sum_{i=1}^{N} O_i\right)\left(\sum_{i=1}^{N} P_i\right)}{\sqrt{\left[N\left(\sum_{i=1}^{N} O_{i\,i}^2\right) - \left(\sum_{i=1}^{N} O_i\right)^2\right]\left[N\left(\sum_{i=1}^{N} P_1^2\right) - \left(\sum_{i=1}^{N} P_i\right)^2\right]}}$$

Equation 5. Pearson Correlation Coefficient

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(P_i - O_i\right)^2}$$

Equation 6. Root Mean Square Error

$$IOA = 1 - \frac{\sum_{i=1}^{N} \left(P_i - O_i\right)^2}{\sum_{i=1}^{N} \left(\left|P_i - O_{mean}\right| + \left|O_i - O_{mean}\right|\right)^2}$$

Equation 7. Index of Agreement

Forecasting results

The reliability of the AHLU forecasts hinges on the accuracy of the HLI forecasts. These ultimately rely on the BoM forecasts. Since any AHLU value also relies on the past behaviour of the HLI (through the accumulation process) any inaccuracies in past HLI predictions will have an impact on the most recent AHLU value, however, any extreme behaviour is curtailed by not permitting its value to become negative.

One further issue that the reader should be aware of is that there is a discontinuity imposed on the data in the form of the various cut-off values, viz. the Thermo-Neutral zone boundaries. The HLI is also limited to a value of 50 should calculations yield a value lower than 50. AHLU values are not permitted to take on negative values. Consequently, any statistical analyses should not be applied indiscriminately and any results arising from such analyses should be interpreted with this in mind.

By way of example, assume that the observed HLI and the one day ahead forecast HLI are being compared. There will be instances when both of these values will be 50, even though calculations would indicate otherwise. This situation indicates perfect correlation between observed and predicted values. There will also be instances when only one of these parameters will be 50. This will result in a number of (say) observed HLI values paired with predicted values which are set to 50 resulting in statistics which may not be representative of the true situation.

The situation is further complicated since two separate equations are used to calculate the HLI value, depending on whether the Black Globe Temperature (BGT) is less than or greater than or equal to 25.

Finally, the quantity of data available for analysis is rather large. There are 16 sites and for each of these sites there are 3 pairs of HLI data sets that can be considered: the observed HLI with each of the one, three and six day ahead forecasts. Also for each of these sites, there are 3 pairs of AHLU data sets, however, these are further subdivided into 6 HLI threshold categories, resulting in 288 pairs of data sets.

In order to keep this report a reasonable length, discussion will be restricted to the general behaviour of the relevant parameters. Any behaviour that warrants further investigation will be discussed in greater detail.

HLI Behaviour

The HLI was calculated using half hourly predictions of wind speed, temperature and relative humidity. If the calculated HLI value fell below 50, it was set to 50. Cloud information and solar radiation were not available, hence solar radiation was calculated using Equation 2. This represents the maximum radiation for the time of year, time of day and latitude of the site. Whilst this will tend to overestimate the actual solar radiation, it has only a minor effect on the predicted HLI because of the logarithmic dependence of HLI on solar radiation. To illustrate this, a factor of 10 change in solar radiation (say from 1000 w/m^2 to 100 w/m^2 or cloudless to very cloudy) will cause a decrease in HLI value of either 4.16 to 4.96, the exact value depending on whether the BGT was below or above 25 respectively.

Appendix B contains a table of the line of best fit and statistical parameters describing the accuracy of the forecasting process. The overall tendency is for the forecast accuracy to decrease as the forecast horizon increases. More detailed comments can be found in Appendix B. The remainder of this section will focus on specific aspects of HLI behaviour.

The Figure 1 depicts a scatter plot of the one day ahead forecasts of HLI plotted against observed HLI for Warwick. There are several features in this graph which merit some comment.

Firstly, the discontinuity in the data due to the lower limit of 50. Secondly, the remaining data are scattered about a straight line of unit slope. Perfect forecasts would have resulted in all the points lying exactly on the line. The scatter about the line results from errors in forecasting and increases as the errors in the forecasts increases. This is typical in plots of observed versus forecast variables. Note also that the data form two distinct groups or clusters – one centred about a HLI value of about 55 and the other centred about a HLI value of 80, representing night time daytime observations/forecasts respectively. Thirdly, there are some data points – the outliers - which are located a substantial distance from the line. Possible explanations for the existence of these are that the forecast technique failed due to exceptional processing conditions (eg an algorithm failed to converge) or missing or erroneous input data.

The above features are present in varying degrees in all the data sets.

Figures 2 and 3 illustrate the variability that can be expected in the data. Figure 2 is the one day ahead and Figure 3 is the six day ahead forecasts plotted against observed HLI for Katanning.

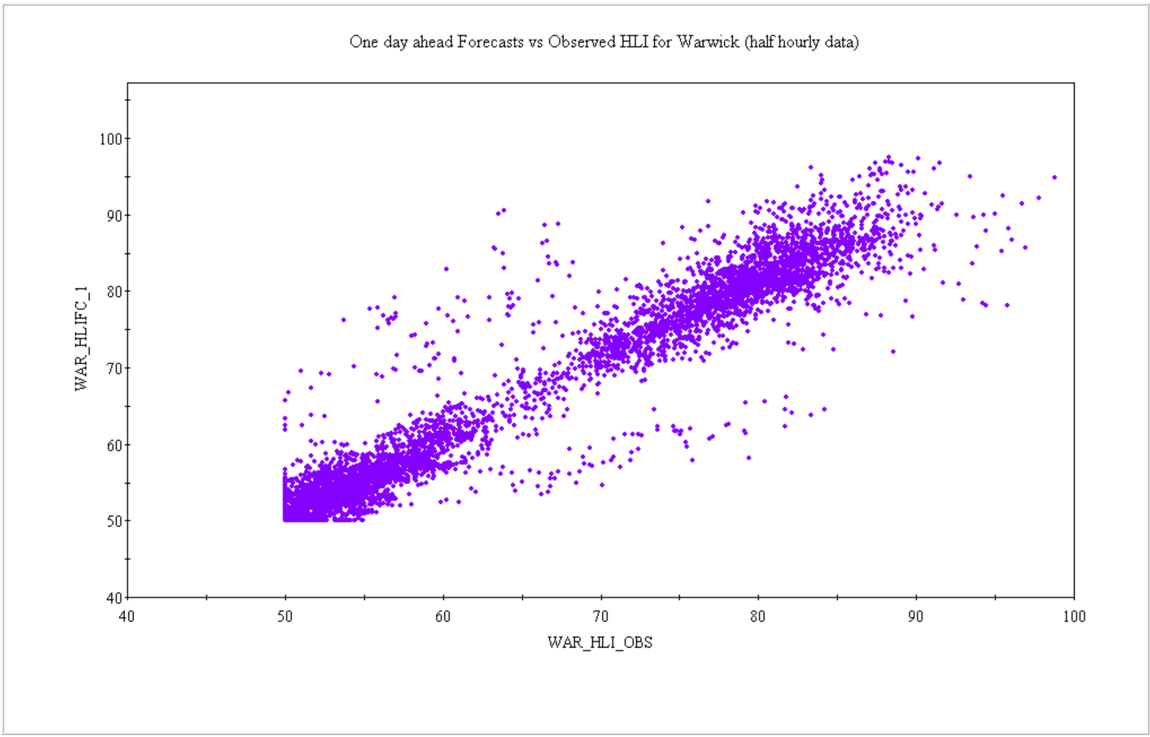

Figure 1: One day ahead forecast versus observed HLI for Warwick.

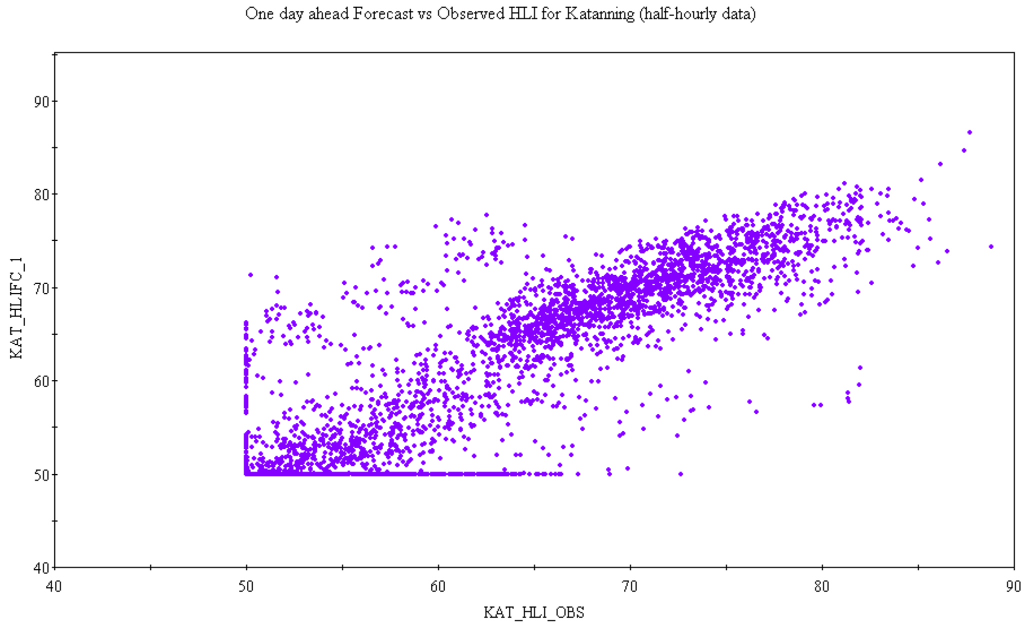

Figure 2: One day ahead forecast versus observed HLI for Katanning.

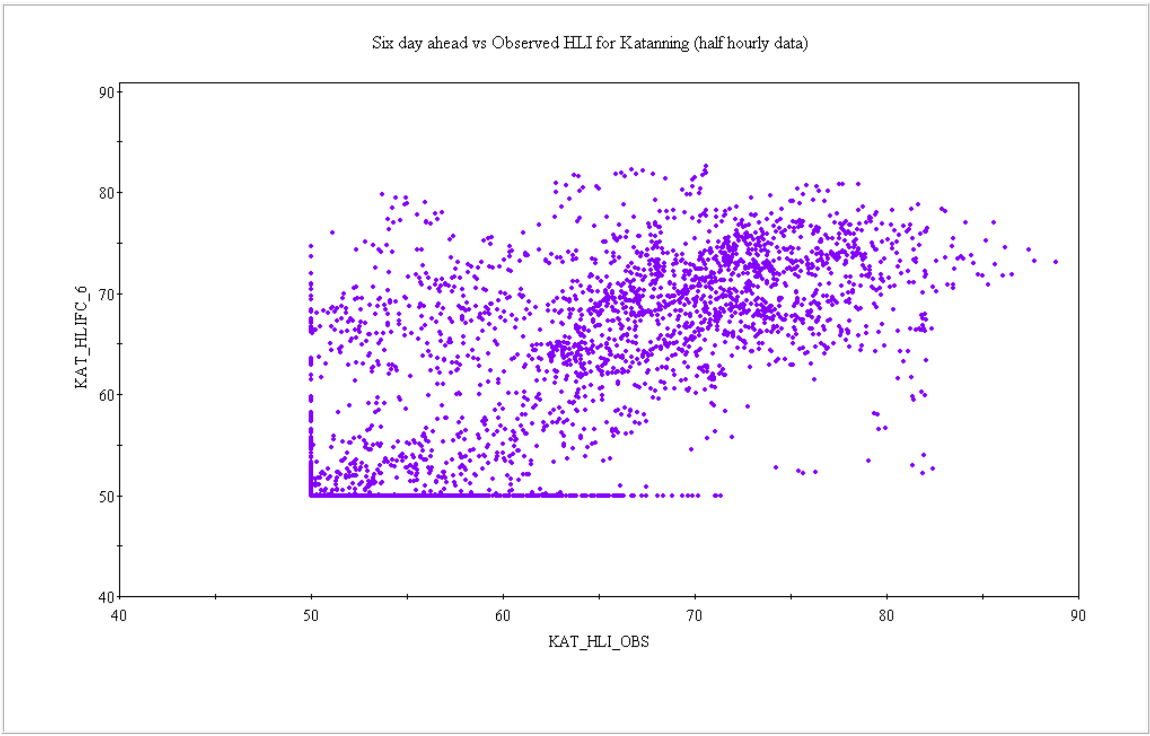

Figure 3: Six day ahead forecast versus observed HLI for Katanning.

Note that the features discussed above are still present but the correlation deteriorates markedly for the six day ahead forecasts.

The temporal characteristics and behaviour of HLI will be discussed in the next section.

AHLU Behaviour

Analyses of AHLU were restricted to those corresponding to an upper HLI threshold of 86. Also, as the daily maximum AHLU value is the parameter of concern, preliminary analyses will concentrate on this variable, progressing to more detailed analyses of half hourly data for specific cases.

Appendix C contains contingency tables for all sites for one, three and six day ahead forecasts for AHLU categories using upper HLI thresholds of 86, 89, 92 and 95. Further discussion on the AHLU trends can be found in Appendix C. The remainder of this section will focus on specific aspects of AHLU behaviour.

The graph in Figure 4 shows the scatter plot of one day ahead forecast versus observed AHLU (half-hourly data) for Amberley and Figure 5 shows the corresponding daily maximum AHLU values. Both these data sets exhibit similar characteristics – firstly, a significant number of points lying on the axes indicating that the AHLU is zero for a sizeable fraction of the time and secondly, that the correlation is poor – ie the performance of the forecasting algorithm is poor.

It should be stressed that even though the performance of the algorithm may be poor in calculating the half hourly values, categorising this into the various risk categories improves the final performance as each category covers a broad range of AHLU values.

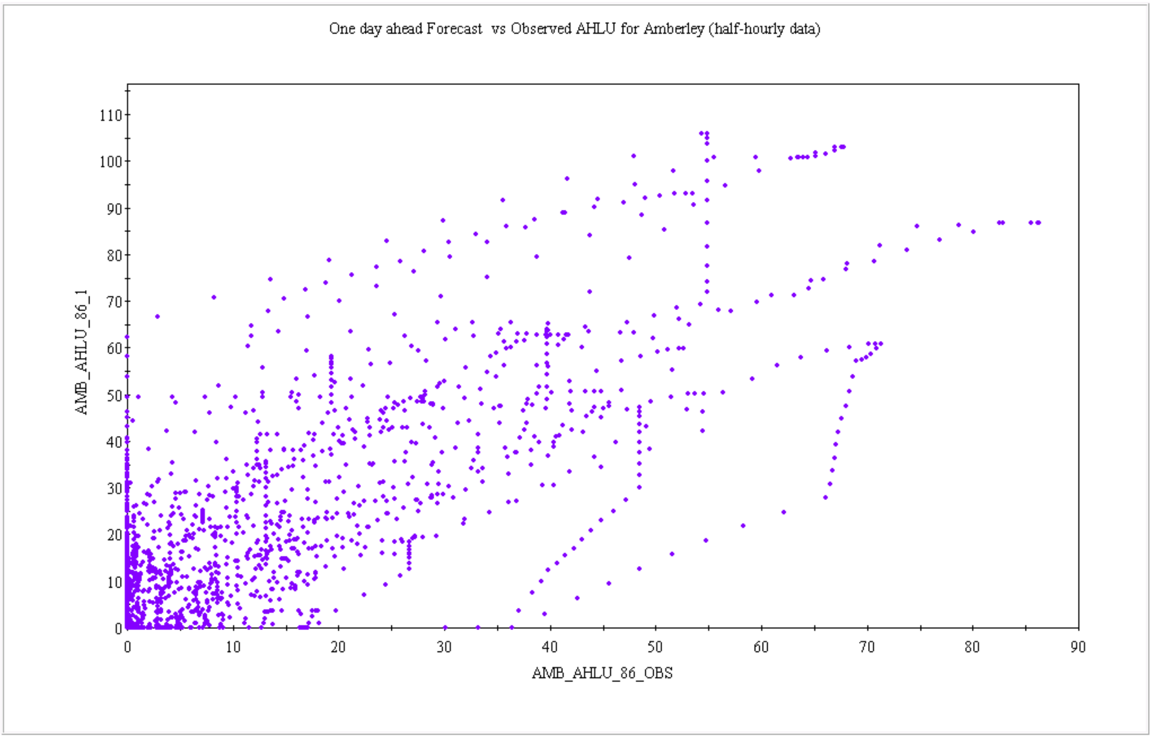

Figure 4: One day ahead forecast versus observed AHLU (half hour average data) for Amberley using a HLI value of 86 for the Thermo-Neutral zone upper limit.

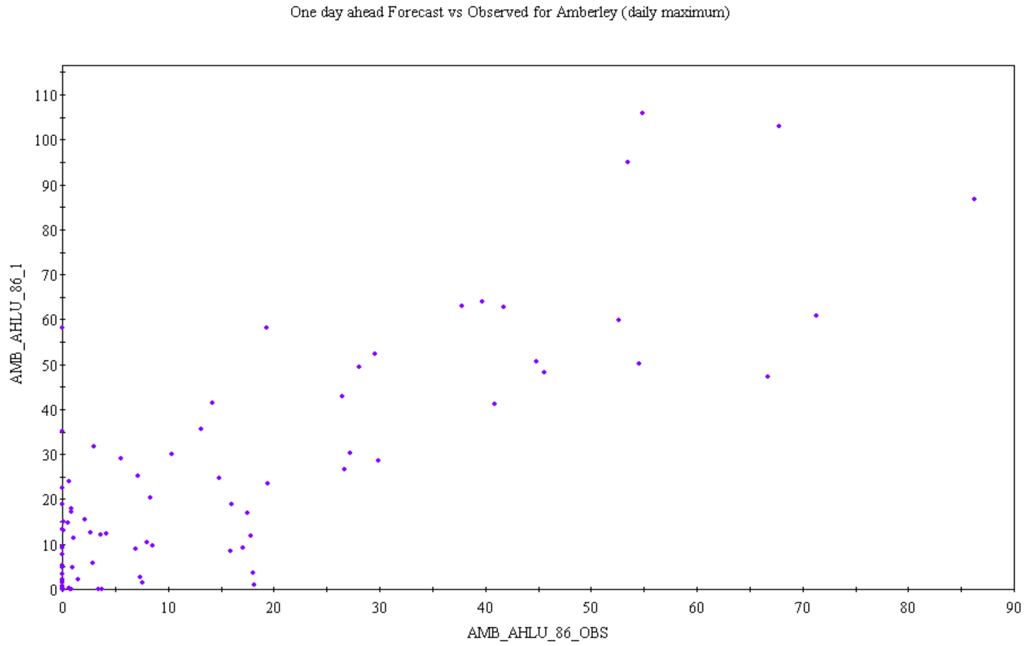

Figure 5: One day ahead forecast versus observed AHLU (daily maximum) for Amberley using a HLI value of 86 for the Thermo-Neutral zone upper limit.

A more useful insight into the forecasting performance can be gleaned from the temporal behaviour. Figures 6 and 7 show the temporal behaviour of the daily maximum AHLU value for Amberley and Warwick using an upper HLI threshold of 86.

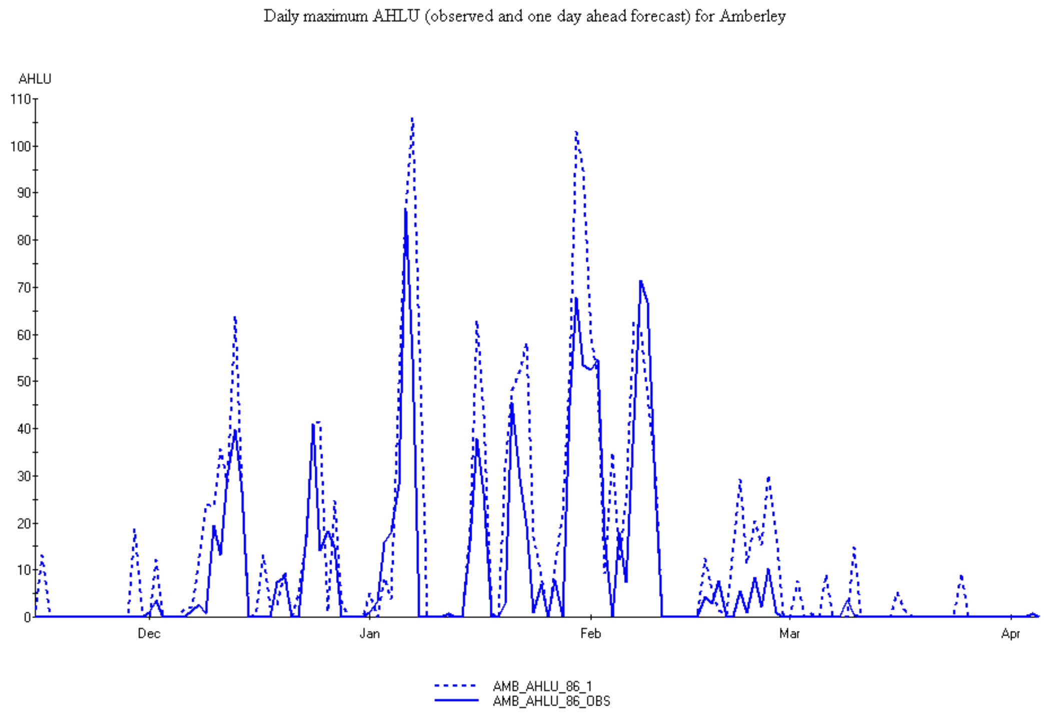

Figure 6: One day ahead forecast versus observed AHLU (daily maximum) for Amberley using a HLI value of 86 for the Thermo-Neutral zone upper limit.

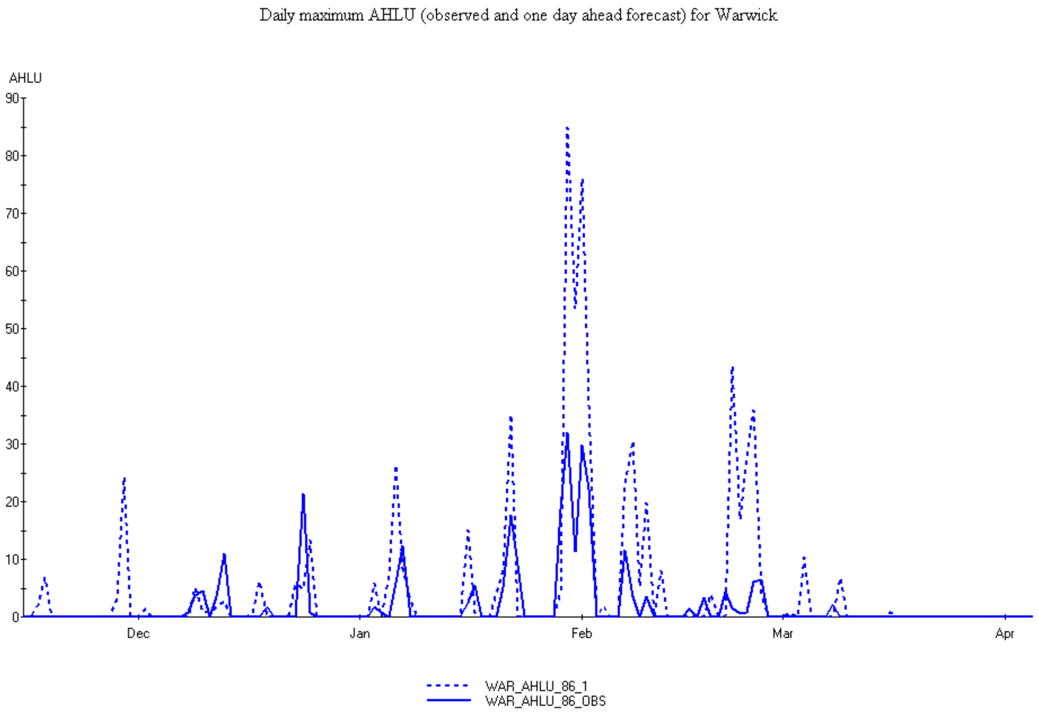

Figure 7: One day ahead forecast versus observed AHLU (daily maximum) for Warwick using a HLI value of 86 for the Thermo-Neutral zone upper limit.

Two features worth noting are firstly, the AHLU tends to sit at a base line value of zero for a fraction of the time with intermittent excursions above this for the remainder. This behaviour is present to varying degrees in all the data sets, being more pronounced at the cooler sites. This tendency is also evident for AHLU parameters calculated using higher upper HLI thresholds. Secondly, there is a tendency for the forecast to mimic the observed data – ie excursions are present in both – with the forecast value tending to be greater than the observed. Again this behaviour is present, to varying degrees, in all data sets.

The issue which now needs to be addressed is the cause of the discrepancy between the observed and forecast AHLU values. Since the AHLU depends only on the HLI, investigation of HLI behaviour for periods when the AHLU forecasts are poor should provide insight into the causes for the poor performance. A detailed investigation was carried out for the period 19 Feb to 28 Feb 2005 (see Figure 8) where significant discrepancies between the forecast and observed AHLU values are evident.

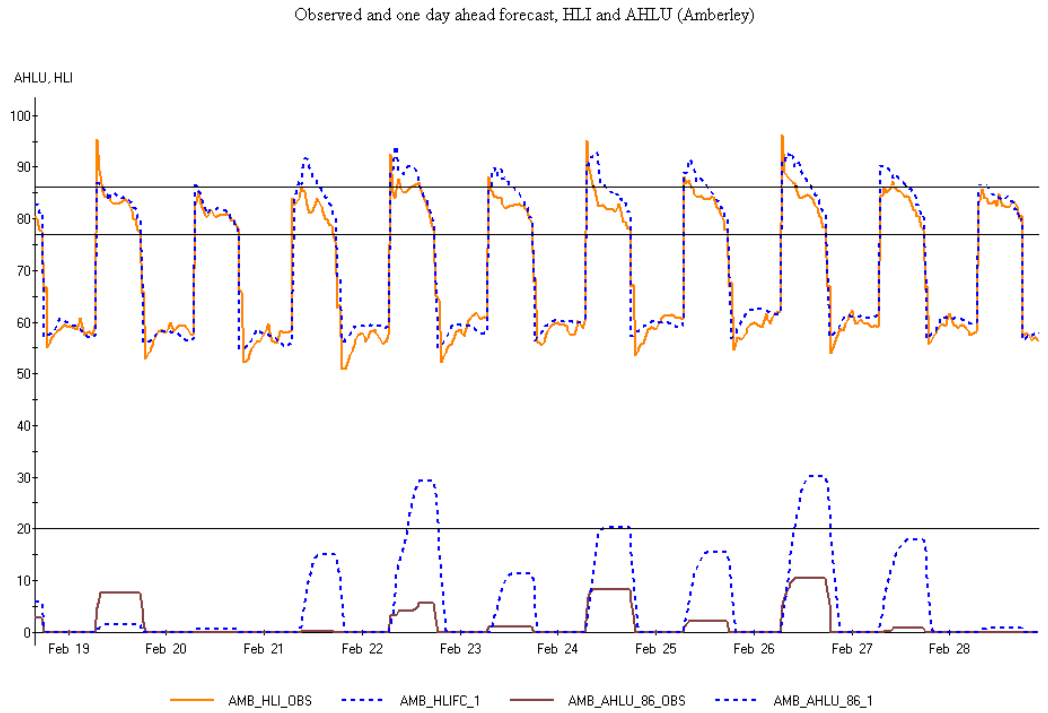

Figure 8: Temporal behaviour of one day ahead forecast versus observed HLI (upper traces) and AHLU (lower traces) for Amberley (half hour data).

Figure 8 depicts the observed and one day ahead forecasts of HLI and AHLU (using an upper HLI threshold of 86) half hourly data for Amberley for the period 19 Feb to 28 Feb 2005. The tick marks on the horizontal axis indicate midnight for the respective dates. The HLI time series constitute the upper traces which show distinctive diurnal variations whilst the two lower traces are the AHLU values. Solid lines are the observed and dotted lines are the forecast values. The three horizontal lines are as follows: the line at an AHLU value of 20 signifies the transition between low and medium risk. The lines at 77 and 86 are the lower and upper HLI thresholds of the Thermo-Neutral zone.

There are several features in the figure which deserve a mention:

This data sample contains examples of both where the observed and forecast HLI values compare favourably and where they compare poorly. The AHLU forecasting performance is consistently poor as indicated by the scatter plots.

Spikes in the observed HLI above 86 occur on the 19, 22, 24 and 26 of February. For all these events, the parameters which were used to determine the HLI (e.g. BGT) vary smoothly and monotonically. This in itself would produce a smoothly varying HLI profile devoid of spikes. On all these occasions however, the wind speed value was zero, and this combined with the exponential term in the HLI formula gave rise to the sharp increase in HLI. Specifically, on these occasions the wind speed decreased over a period of about one hour, attained a value of zero and then increased again – as though there was a lull in observed wind speed at this time.

There were also instances where the wind speed was zero for a single half hour record, suggesting that the data may be in error (ie not recorded) rather than the wind speed actually dropping to zero for that brief period of time.

The forecast AHLU on two occasions significantly exceeded the observed AHLU to the extent that the observed AHLU was well within the Low Risk category whilst the forecast AHLU had progressed to the Medium Risk category. This coincided with periods when the disagreement between observed and forecast HLI was most pronounced and also when one of these parameters was above and the other below the upper HLI threshold (in this case 86). It is not clear whether this sharp cutoff is the intended behaviour or whether a more smoothly varying transition would be preferable.

Inspection of Figure 8 reveals that the HLI spends a significant fraction of the time at either the daytime or night time value with a relatively short transition period between these. This gives rise to the two clusters observed in the scatter plots of Figures 1, 2 and 3.

Finally, the behaviour of the parameters that were utilised in the HLI calculation were investigated. These are solar radiation, temperature (both of which are used to calculate Black Globe Temperature), the wind speed and relative humidity. These are shown in Figures 9, 10 and 11. It is evident that whilst the models are capable of forecasting Black Globe Temperature and relative humidity with confidence, the forecasting of wind speed is decidedly poor. It is not clear at this stage what the causes for this behaviour might be. Unfortunately, investigation into this behaviour of the models is currently beyond the scope of this report however, it is an issue which should be addressed as soon as possible.

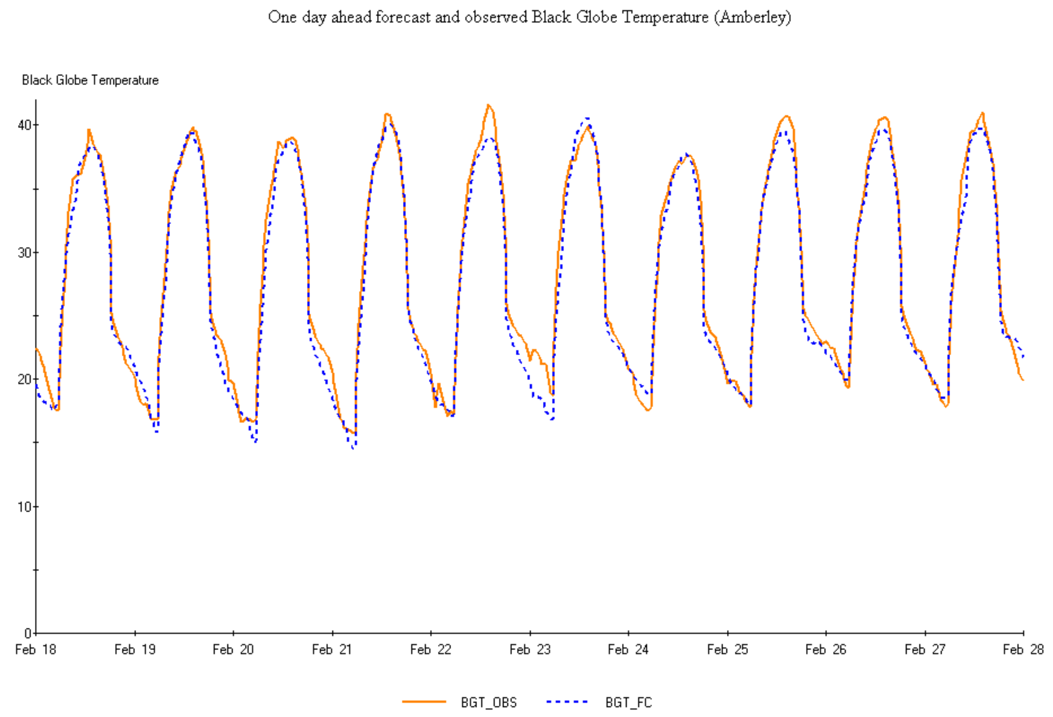

Figure 9: One day ahead forecast and observed Black Globe Temperature (half hourly data) for Amberley.

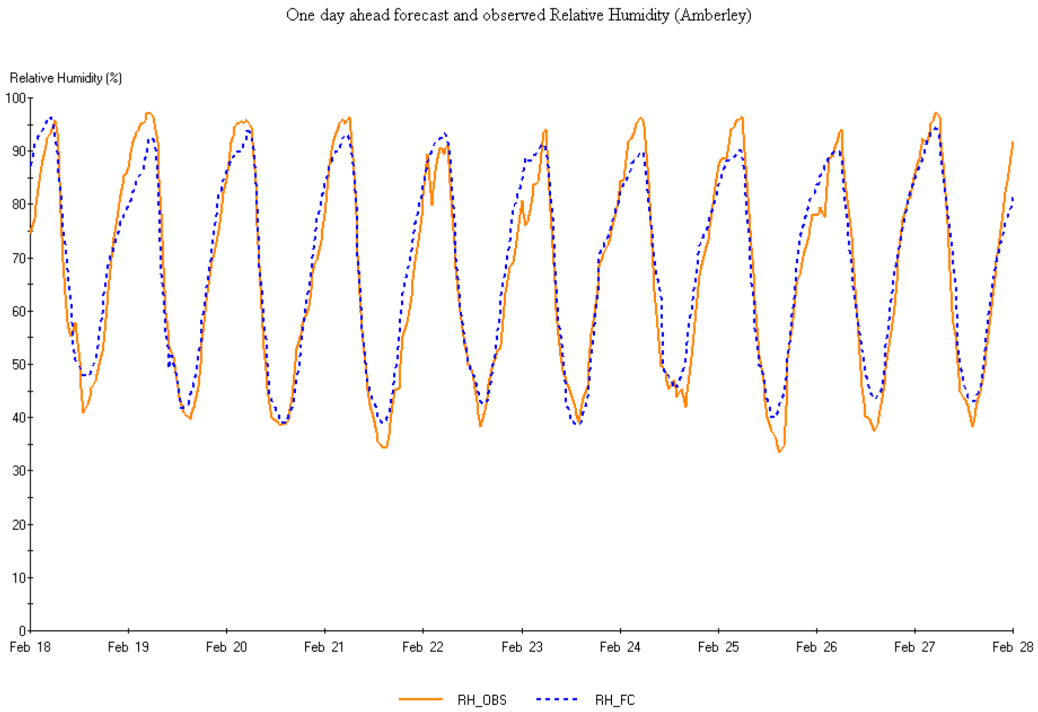

Figure 10: One day ahead forecast and observed Relative Humidity (half hourly data) for Amberley.

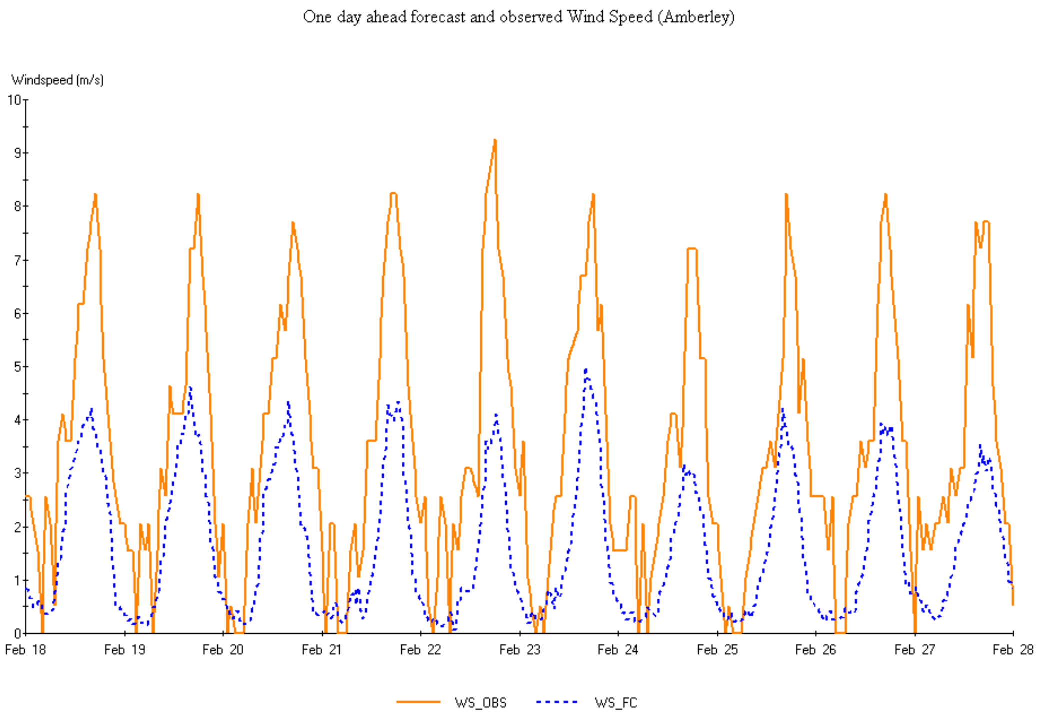

Figure 11: One day ahead forecast and observed Wind Speed (half hourly data) for Amberley.

Service delivery and utility

Forecasts of the following parameters were checked by the Katestone Environmental staff and posted to the web site www.katestone.com.au/mla on a daily basis:

- Tables of previous six days' AHLU values obtained using HLI thresholds of 80, 83, 86,…95;
- Tables of previous six days' minimum and maximum daily HLI value;
- Tables of previous six days' rainfall;
- Tables of six day forecasts of the above parameters; and
- Graphs of six day forecasts of HLI and AHLU for HLI thresholds of 80, 83,…95.

These forecasts were transferred to the web site on a daily basis for access by all feedlot operators. The previous six days' forecasts were also made available should the feedlot operators need to check an earlier forecast.

The implementation of the forecast model is very flexible. Any future need for forecasting at these same locations will require only a basic retraining of the models with more recent data. The addition of new sites would require correspondence with the Bureau of Meteorology in order to make the additional data available. Katestone Environmental would then need to extend the existing models to incorporate the new sites.

Recommendations for future work

It is recommended that earlier advice is necessary on the need for any new forecasting sites to ensure an ample amount of concurrent upper-level and AWS data are available to train the models. This will improve the initial forecast accuracy of the models.

No allowance has currently been made for the difference between feedlot conditions and conditions at the AWS site, or for factors such as shading. These factors could readily be included when results of other studies are available.

As heat stress management in cattle is an ongoing area of research, future projects should include up to date methods for calculating heat stress in cattle and reporting these on a regular basis. Also, since cattle can adapt to heat stress to a limited extent, (Leonard et al (2001)), calculation of parameters relating to the state of cattle as a result of previous heat stress should also be investigated and incorporated into the modelling.

Conclusions

A system using revised equations for forecasting the HLI (which now incorporates wind speed) and the AHLU has been developed and trialled over the 2004-2005 summer period. Modelling of the various input parameters was performed on a half hourly basis for each of the feedlot sites using the Bureau of Meteorology LAPS and GASP forecasts. The parameters which were generated were the temperature, wind speed and dew point. The solar radiation was calculated analytically from the date, time of day and latitude of the site.

In terms of intermediate or calculated parameters, the temperature and dew point were used to calculate the relative humidity. The temperature and solar radiation were used to calculate the Black Globe Temperature; and finally, the Black Globe Temperature and wind speed were used to obtain a value for the HLI.

It was found that the model performed reasonable well in forecasting the temperature and relative humidity. Forecasting of windspeed was relatively poor and this gave rise to over-estimates of HLI and in turn the AHLU. This particular aspect of the modelling requires further investigation.

Finally, although the forecast AHLU values were higher than the values obtained from observations, the performance in predicting the AHLU categories is good and is more important than predicting the actual AHLU value.

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APPENDIX A

Description of Model

A1 Preliminary considerations

The first step in producing site-specific weather forecasts takes advantage of detailed information made readily available from well-proven numerical models in association with determined correlations of local weather variables with such numerical forecasts. the direct predictions from the traditional numerical modelling may be very useful for some variables under normal conditions but are unlikely to properly predict the detailed diurnal variations of key parameters required for constructing heat comfort indices.

Some type of expert system is needed to improve such forecasts. This could involve, for example, the use of more detailed or a wide variety of numerical models to give greater confidence in predictions or alternatively the use of a trained meteorologist to be able to estimate the likely differences between feedlot conditions and those forecast by the numerical model.

An automated approach would utilise the available database of concurrent site measurements and upper-level forecasts to determine statistically significant correlations. These correlations are then assumed to hold over forthcoming events and are used with numerical forecasts to predict feedlot conditions over the next 48-144 hours. The predicted time history of individual meteorological variables can then be combined in various ways to give a time history of a selected thermal comfort index. These index values can be screened against critical thresholds determined from field studies in order to give suitable alarms for various types of likely animal reactions.

This “downscaling” methodology (i.e. relying on a correlation procedure to produce site-specific values from a regional model prediction of atmospheric profiles) has been shown by experience elsewhere to require at least a period of 1-3 months of training data before adequate results are obtained and thereafter a regular retraining over a one year period to produce optimal results. the correlations themselves are only as good as the database upon which they are based.

For general predictions, a short database may suffice as relatively simple relationships are likely to be useful for normal conditions. Extreme conditions are less frequently encountered and may not be present in a short-term database. Given that there is considerable variability between years in general weather conditions (and even more so for extreme events), there is no guarantee that the recent past is a good guide to the forecasting of a series of adverse days, as required in heatwave analysis. The accuracy of the downscaling methodology in heatwave conditions is reliant on the ability of numerical models to accurately predict fluctuations in parameters outside the ranges for which they have been optimised and hence is expected to be limited.

A2 Available data

Over the past 30 years, many field and theoretical studies have demonstrated the sensitivity of near-surface meteorological conditions to changes in local and regional terrain characteristics. Temperatures are very sensitive to terrain elevation, distance from the nearest coastline and vegetation cover. Relative humidity is sensitive to the presence of vegetation cover, local water bodies or the coastline. Wind speed is strongly influenced by the presence of trees, hills or valleys, inland location and the aerodynamic roughness of land within 1 km of the weather station.

In contrast, numerical weather prediction models (regional forecast models) use relatively coarse terrain and land-use information and are very unlikely to capture the influences of the surface characteristics within 1-3 km of the site. On the other hand, on-site measurements will show directly the influences of the local environment by the presence of strong diurnal patterns in wind and, to a lesser extent, temperature variables. On-site weather information is often very important, especially if the nearest BoM automatic weather station is over 15-20 km away or if the feedlot environment is unusual compared to that of the region (say within 25 km).

There are several Australian agencies (hereafter referred to as “service providers”) that routinely run numerical models that could be suitable for either direct forecasts or in conjunction with an expert system using local meteorological information (that is, the prediction of parameter values at a given point from values predicted over a broader scale). These include:

The BoM operates the Global Analysis and Prediction Scheme (GASP) and Limited Area Prediction System (LAPS) models on a regular basis for their Australia-wide weather prediction service. The LAPS model covers an area of Australasia, South East Asia and much of the Indian and Pacific Oceans at various resolutions. The finest resolution (5 km) is only currently used in research work or for the use of the internal BoM consulting arm. The 25 km resolution forms the basis of most publicly-available forecasts.

The information available from these forecasts that is most applicable to the current project includes surface level (screen height) temperature, dew point, sensible and latent heat fluxes, total heat flux and a set of upper-level temperature, dew point and wind components.

By special arrangements, these forecasts can be provided for any given grid point on a three-hourly basis out to a prediction horizon of 48 hours. They do not generally take account of local weather station data from the nearest BoM AWS site. The numerical forecasts from the model are not edited or screened for reliability and are from one model run.

The GASP model provides a similar set of temperature and wind variables at a coarser resolution of 75 km on a twelve-hourly basis to a time horizon of 6 days. No local data assimilation is included at this scale.

The numerical model results can be made available relatively cheaply on a dedicated web site. Various energy companies have used such information over the past 4 years (using the Katestone downscaling software) as a basis for demand prediction and trading activities. The service has proved to be very reliable with only very infrequent excursions in some parameters. The BoM model accuracy is reported in various BoM publications.

The CSIRO runs a different type of numerical model on a regular basis for a current trial service for agricultural and energy users. The model is run at a resolution of 5 km or better to a time horizon of 8 days. The predicted variables include rainfall and cloud cover, as well as the standard temperature, wind and moisture variables.

The University of New South Wales provides a commercial prediction system to a time horizon of 7-10 days at spatial resolution to 1 km. Their approach is claimed to be a more refined model than the operational models used by the BoM and can include site-specific data assimilation. The support services and reliability are less clear as they depend on staff availability but several publications have been produced showing the very satisfactory performance in extreme events (e.g. bushfires, air quality and sailing forecasts).

A3 Description of model

The system that was implemented was strongly based on a pre-existing and proven scheme developed by Katestone Scientific for use in energy forecasting. It consists of the following steps:

Obtain upper-level forecast data from numerical weather prediction models via a special web-site provided by the BoM.

Collect concurrent information from an automatic weather station close to the site of interest.

Once a sufficient training set of information is collected, use proprietary Katestone software to develop statistical models that relate the surface measurement to a subset of the upper-level variables.

Use these models and the most recent data to provide the necessary forecasts.

The process is illustrated in Figure A1.

Past experience has shown that an accounting of natural diurnal and seasonal cycles together with a partitioning of the data into half-hourly time steps allows relatively simple linear regression techniques to be used, rather than more complex hybrid statistical/neural network schemes often used.

The robustness of this approach was demonstrated by the error statistics Table A1 obtained for a period of one year for various parameters and the location of Sydney and Brisbane. For example, there is a pleasing performance for temperature and windspeed, with only minor seasonal variations and the expected slow decrease in accuracy with an increasing prediction horizon.

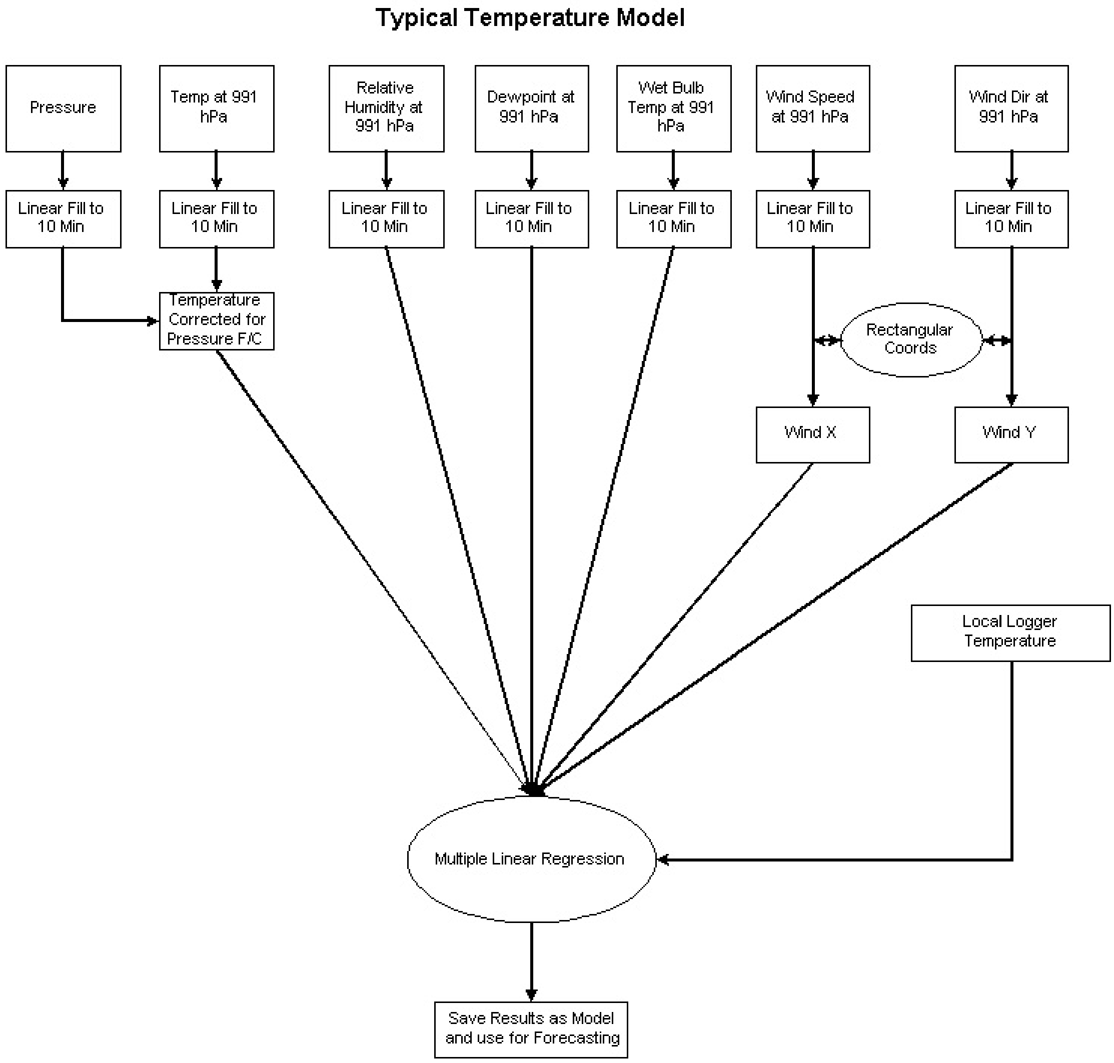

Figure A1: Example of process of using LAPS/GASP data (e.g. 991 hpa parameters) in downscaling to give a surface temperature forecast

Variable	Season	Forecast horizon		
		1 - 2 days	**3 - 4 days**	**5 - 6 days**
Sydney Temp (°C)	Summer	1.44	1.78	2.15
	Autumn	1.26	1.72	1.88
	Winter	1.27	1.52	1.71
	Spring	1.37	1.61	2.23
Sydney Wind Speed (m/s)	Summer	1.62	1.84	1.95
	Autumn	1.54	1.56	1.60
	Winter	1.44	1.74	1.68
	Spring	1.86	2.03	2.09

Table A1: Mean Absolute Error for Sydney and Brisbane forecasts

APPENDIX B:

Overall Behaviour of the HLI

The performance of the forecasting model was characterised using (a) a line of best fit, (Slope and Intercept) (b) the Pearson Correlation Coefficient, (c) the Root Mean Square Error (RMSE), (d) the Index of Agreement (IOA) and (e) the Bias. The Bias is obtained by summing the difference between the predicted and observed quantities and dividing by the number of samples. Although it is not, strictly speaking, a statistical measure, it does give insight into whether the model is under predicting (negative bias) or over predicting (positive bias).

The following table (Table B1) lists the above parameters for the one, three and six day ahead forecasts. The parameters include the three statistical measures, the bias and the slope and intercept of the line of best fit of the forecast vs observed quantities. The column labelled “Count” reports how many data points were processed to produce the associated statistical measures. All data points where either of the observed or forecast HLI were equal to 50 were omitted.

Features worth noting are:

- All statistics show the same behaviour – forecasting performance deteriorates as the forecast horizon increases.

- The Bias indicates that the model, in general, over predicts. This results in an over prediction of the AHLU.

Katanning performed poorly on most measures, however the bias (one of the few negative biases) does not stand out. Charleton, the last site to be added to the forecasting service and, consequently with little data for purposes of training the model, performed surprisingly well.

Table B1: HLI statistics for 2004-2005 summer period

Site	Slope	Intercept	Pearson	RMSE	IOA	Bias	Count
One day ahead forecasts							
Albury	0.96	3.94	0.9	0.08	0.94	1.1	3599
Amberley	0.98	2.19	0.95	0.06	0.97	1.05	5487
Armidale	0.93	5.75	0.89	0.08	0.94	1.14	3035
Charleton	0.94	3.74	0.89	0.08	0.94	-0.52	2797
Clare	0.97	2.59	0.87	0.09	0.93	0.91	2913
Emerald	0.97	2.31	0.94	0.06	0.97	0.08	5397
Griffith	0.92	5.18	0.91	0.07	0.96	-0.17	3250
Hay	0.89	7	0.89	0.09	0.94	-0.37	2436
Katanning	0.79	13.21	0.83	0.09	0.91	-0.93	2765
Miles	0.95	4.22	0.92	0.08	0.95	0.85	4996
Moree	0.96	3.73	0.91	0.08	0.95	1.03	3981
Oakey	0.92	4.87	0.95	0.06	0.97	-0.47	4446
Roma	0.94	5.2	0.92	0.07	0.96	1.01	4469
Tamworth	0.95	4.14	0.93	0.07	0.96	0.57	3521
Warwick	1.01	0.77	0.96	0.06	0.98	1.14	4869
Yanco	0.95	4.37	0.92	0.07	0.95	0.66	3359
Three day ahead forecasts							
Albury	0.93	7.52	0.85	0.12	0.9	2.9	3205
Amberley	0.95	3.65	0.89	0.09	0.94	0.32	4861
Armidale	0.92	8.32	0.82	0.13	0.88	2.91	2760
Charleton	0.9	8.18	0.69	0.17	0.8	1.6	2593
Clare	0.91	8.39	0.8	0.12	0.88	2.17	2612
Emerald	0.96	3.01	0.9	0.08	0.95	-0.13	4869
Griffith	0.84	12.08	0.81	0.1	0.9	1	2843
Hay	0.75	19.07	0.8	0.13	0.88	1.54	2147
Katanning	0.68	20.58	0.74	0.12	0.86	-0.97	2447
Miles	0.91	7.25	0.88	0.09	0.94	0.73	4590
Moree	0.84	13.79	0.86	0.1	0.92	2.32	3546
Oakey	0.9	7.33	0.91	0.08	0.95	0.47	3998
Roma	0.88	10.32	0.87	0.1	0.92	1.86	4136
Tamworth	0.9	9.28	0.88	0.11	0.93	2.54	3159
Warwick	0.95	4.29	0.91	0.08	0.95	1.14	4470
Yanco	0.86	12.07	0.83	0.11	0.9	2.16	2967
Six day ahead forecasts							
Albury	0.86	13.45	0.76	0.15	0.85	3.68	3031
Amberley	0.92	5.24	0.87	0.1	0.93	-0.21	4506
Armidale	0.85	12.34	0.76	0.15	0.85	2.62	2585
Charleton	0.74	18.51	0.58	0.19	0.74	1.05	2425
Clare	0.75	17.66	0.64	0.16	0.79	1.14	2415
Emerald	0.94	3.73	0.88	0.09	0.94	-0.39	4731
Griffith	0.76	18.21	0.72	0.13	0.84	1.46	2705
Hay	0.71	22.93	0.71	0.17	0.82	2.86	2035
Katanning	0.48	34.65	0.54	0.16	0.74	0.11	2276
Miles	0.87	9.17	0.84	0.11	0.91	0.12	4427
Moree	0.82	15.18	0.82	0.12	0.89	2.27	3391
Oakey	0.88	8.48	0.88	0.09	0.94	-0.07	3831
Roma	0.87	10.49	0.84	0.11	0.91	1.05	3928
Tamworth	0.87	11.46	0.85	0.12	0.91	2.1	2970
Warwick	0.93	5.63	0.89	0.09	0.94	0.58	4290
Yanco	0.75	19.74	0.71	0.14	0.82	2.59	2767

APPENDIX C

Overall Behaviour of the AHLU

The performance of the forecasting model is presented as a collection of contingency tables contained in Tables C1 through to C4 for one, three and six day ahead forecasts for the four risk categories. Table C1 is for HLI cutoff of 86, C2 corresponds to 89 etc. In the contingency tables, the horizontal represents the observed and the vertical represents the forecast AHLU category. All entries in the contingency tables are percentages.

The noteworthy features are that:

- The AHLU values obtained using the higher upper HLI thresholds are predominantly in the Low Risk category for both observed and forecast values.
- The performance of the forecasting model in predicting the AHLU categories is quite good.
- The overall behaviour reflects the observations reported elsewhere in this report – there is a tendency to over predict and that prediction performance (arising from the poor HLI forecasting) is not optimal.

Finally, since only one datum per day is available for the daily maximum, any statistics obtained from such data sets may not reveal trends that would otherwise be evident were a larger quantity of data available.

Table C1: HLI cut-off of 86

Contingency tables of forecast vs observed AHLU for a HLI cutoff of 86												
	One day ahead				**Three day ahead**				**Six day ahead**			
Albury												
Extreme	0	0	0	0	0	0	0	0	0	0	0	0
High	0	0	0	0	0	0	0	0	1.4	0	0	0
Medium	0	0	0	0	0.7	0	0	0	5.6	0	0	0
Low	100	0	0	0	99.3	0	0	0	93	0	0	0
	Low	Medium	High	Extreme	Low	Medium	High	Extreme	Low	Medium	High	Extreme
Armidale												
Extreme	0	0	0	0	0	0	0	0	0	0	0	0
High	0	0	0	0	0	0	0	0	0	0	0	0
Medium	0	0	0	0	0.7	0	0	0	0.7	0	0	0
Low	100	0	0	0	99.3	0	0	0	99.3	0	0	0
	Low	Medium	High	Extreme	Low	Medium	High	Extreme	Low	Medium	High	Extreme
Griffith												
Extreme	0	0	0	0	0	0	0	0	0	0	0	0
High	0	0	0	0	0	0	0	0	0	0	0	0
Medium	0	0	0	0	0	0	0	0	0.7	0	0	0
Low	100	0	0	0	100	0	0	0	99.3	0	0	0
	Low	Medium	High	Extreme	Low	Medium	High	Extreme	Low	Medium	High	Extreme

Contingency tables of forecast vs observed AHLU for a HLI cutoff of 86												
	One day ahead				Three day ahead				Six day ahead			
Hay												
Extreme	0	0	0	0	0	0	0	0	0	0	0	0
High	0.7	0	0	0	0	0	0	0	0	0	0	0
Medium	3.5	0	0	0	0.7	0	0	0	1.4	0	0	0
Low	95.8	0	0	0	99.3	0	0	0	98.6	0	0	0
	Low	Medium	High	Extreme	Low	Medium	High	Extreme	Low	Medium	High	Extreme
Moree												
Extreme	0	0	0	0	0	0	0	0	0	0	0	0
High	1.4	0	0	0	0.7	0	0	0	0	0	0	0
Medium	4.2	0	0	0	5.6	0	0	0	2.8	0	0	0
Low	94.4	0	0	0	93.7	0	0	0	97.2	0	0	0
	Low	Medium	High	Extreme	Low	Medium	High	Extreme	Low	Medium	High	Extreme
Tamworth												
Extreme	0	0	0	0	0	0	0	0	0	0	0	0
High	0	0	0	0	0	0	0	0	0.7	0	0	0
Medium	2.1	0	0	0	5.6	0	0	0	0.7	0	0	0
Low	97.9	0	0	0	94.4	0	0	0	98.6	0	0	0
	Low	Medium	High	Extreme	Low	Medium	High	Extreme	Low	Medium	High	Extreme

Contingency tables of forecast vs observed AHLU for a HLI cutoff of 86												
	One day ahead				**Three day ahead**				**Six day ahead**			
Yanco												
Extreme	0	0	0	0	0	0	0	0	0	0	0	0
High	0	0	0	0	0	0	0	0	0	0	0	0
Medium	1.4	0	0	0	0.7	0	0	0	3.5	0	0	0
Low	98.6	0	0	0	99.3	0	0	0	96.5	0	0	0
	Low	Medium	High	Extreme	Low	Medium	High	Extreme	Low	Medium	High	Extreme
Katanning												
Extreme	0	0	0	0	0	0	0	0	0	0	0	0
High	0	0	0	0	0	0	0	0	0	0	0	0
Medium	0	0	0	0	0	0	0	0	0	0	0	0
Low	100	0	0	0	100	0	0	0	100	0	0	0
	Low	Medium	High	Extreme	Low	Medium	High	Extreme	Low	Medium	High	Extreme
Charleton												
Extreme	0	0	0	0	4.9	0	0	0	2.8	0	0	0
High	0	0	0	0	0	0	0	0	0	0	0	0
Medium	0	0	0	0	0.7	0	0	0	0.7	0	0	0
Low	100	0	0	0	94.4	0	0	0	96.5	0	0	0
	Low	Medium	High	Extreme	Low	Medium	High	Extreme	Low	Medium	High	Extreme

Contingency tables of forecast vs observed AHLU for a HLI cutoff of 86												
	One day ahead				**Three day ahead**				**Six day ahead**			
Clare												
Extreme	0	0	0	0	0	0	0	0	0	0	0	0
High	0	0	0	0	0	0	0	0	0	0	0	0
Medium	0.7	0	0	0	0	0	0	0	2.1	0	0	0
Low	99.3	0	0	0	100	0	0	0	97.9	0	0	0
	Low	Medium	High	Extreme	Low	Medium	High	Extreme	Low	Medium	High	Extreme
Amberley												
Extreme	0	0	1.4	0	2.8	2.8	1.4	0	2.1	0	0.7	0
High	1.4	3.5	3.5	0	3.5	0.7	1.4	0	2.8	2.1	0	0
Medium	8.5	4.9	0.7	0	4.9	2.8	1.4	0	5.6	1.4	2.1	0
Low	76.1	0	0	0	74.6	2.1	1.4	0	75.4	4.9	2.8	0
	Low	Medium	High	Extreme	Low	Medium	High	Extreme	Low	Medium	High	Extreme
Emerald												
Extreme	0	1.4	1.4	0	2.1	2.1	1.4	0	4.9	3.5	0.7	0
High	1.4	8.5	0	0	2.8	4.9	0	0	2.1	2.1	0.7	0
Medium	5.6	4.9	0	0	7.7	4.2	0	0	4.9	4.2	0	0
Low	75.4	1.4	0	0	69.7	4.9	0	0	70.4	6.3	0	0
	Low	Medium	High	Extreme	Low	Medium	High	Extreme	Low	Medium	High	Extreme

Contingency tables of forecast vs observed AHLU for a HLI cutoff of 86												
One day ahead					**Three day ahead**				**Six day ahead**			
Miles												
Extreme	0	0	1.4	0	0	0.7	1.4	0	0	0	0	0
High	0.7	1.4	2.1	0.7	2.1	1.4	2.1	0.7	4.2	0.7	0.7	0
Medium	12	3.5	0.7	0	10.6	1.4	0.7	0	8.5	0.7	1.4	0
Low	75.4	1.4	0.7	0	75.4	2.8	0.7	0	75.4	4.9	2.8	0.7
	Low	Medium	High	Extreme	Low	Medium	High	Extreme	Low	Medium	High	Extreme
Oakey												
Extreme	0	0	0	0	0	0	0	0	0	0	0	0
High	0	0	0	0	0	0	0	0	0	0	0	0
Medium	1.4	0.7	0	0	2.1	0	0	0	0.7	0	0	0
Low	97.2	0.7	0	0	96.5	1.4	0	0	97.9	1.4	0	0
	Low	Medium	High	Extreme	Low	Medium	High	Extreme	Low	Medium	High	Extreme
Roma												
Extreme	0	0	0	0	0	0	0	0	0	0	0	0
High	0.7	0	0	0	3.5	0	0	0	1.4	0	0	0
Medium	8.5	0.7	0	0	6.3	0	0	0	3.5	0.7	0	0
Low	88.7	1.4	0	0	88	2.1	0	0	93	1.4	0	0
	Low	Medium	High	Extreme	Low	Medium	High	Extreme	Low	Medium	High	Extreme

Contingency tables of forecast vs observed AHLU for a HLI cutoff of 86												
	One day ahead				Three day ahead				Six day ahead			
Warwick												
Extreme	0	0	0	0	0	0	0	0	0	0	0	0
High	0.7	1.4	0	0	1.4	0	0	0	0.7	0	0	0
Medium	5.6	0.7	0	0	5.6	0.7	0	0	4.9	0.7	0	0
Low	90.8	0.7	0	0	90.1	2.1	0	0	91.5	2.1	0	0
	Low	Medium	High	Extreme	Low	Medium	High	Extreme	Low	Medium	High	Extreme

Table C2: HLI cut-off of 89

Contingency tables of forecast vs observed AHLU for a HLI cut-off of 89												
	One day ahead				**Three day ahead**				**Six day ahead**			
Albury												
Extreme	0	0	0	0	0	0	0	0	0	0	0	0
High	0	0	0	0	0	0	0	0	0	0	0	0
Medium	0	0	0	0	0	0	0	0	0.7	0	0	0
Low	100	0	0	0	100	0	0	0	99.3	0	0	0
	Low	Medium	High	Extreme	Low	Medium	High	Extreme	Low	Medium	High	Extreme
Armidale												
Extreme	0	0	0	0	0	0	0	0	0	0	0	0
High	0	0	0	0	0	0	0	0	0	0	0	0
Medium	0	0	0	0	0	0	0	0	0	0	0	0
Low	100	0	0	0	100	0	0	0	100	0	0	0
	Low	Medium	High	Extreme	Low	Medium	High	Extreme	Low	Medium	High	Extreme
Griffith												
Extreme	0	0	0	0	0	0	0	0	0	0	0	0
High	0	0	0	0	0	0	0	0	0	0	0	0
Medium	0	0	0	0	0	0	0	0	0	0	0	0
Low	100	0	0	0	100	0	0	0	100	0	0	0
	Low	Medium	High	Extreme	Low	Medium	High	Extreme	Low	Medium	High	Extreme

Contingency tables of forecast vs observed AHLU for a HLI cut-off of 89												
	One day ahead				Three day ahead				Six day ahead			
Hay												
Extreme	0	0	0	0	0	0	0	0	0	0	0	0
High	0	0	0	0	0	0	0	0	0	0	0	0
Medium	0.7	0	0	0	0	0	0	0	0	0	0	0
Low	99.3	0	0	0	100	0	0	0	100	0	0	0
	Low	Medium	High	Extreme	Low	Medium	High	Extreme	Low	Medium	High	Extreme
Moree												
Extreme	0	0	0	0	0	0	0	0	0	0	0	0
High	0	0	0	0	0	0	0	0	0	0	0	0
Medium	1.4	0	0	0	0.7	0	0	0	0.7	0	0	0
Low	98.6	0	0	0	99.3	0	0	0	99.3	0	0	0
	Low	Medium	High	Extreme	Low	Medium	High	Extreme	Low	Medium	High	Extreme
Tamworth												
Extreme	0	0	0	0	0	0	0	0	0	0	0	0
High	0	0	0	0	0	0	0	0	0	0	0	0
Medium	1.4	0	0	0	0	0	0	0	0.7	0	0	0
Low	98.6	0	0	0	100	0	0	0	99.3	0	0	0
	Low	Medium	High	Extreme	Low	Medium	High	Extreme	Low	Medium	High	Extreme

Contingency tables of forecast vs observed AHLU for a HLI cut-off of 89												
	One day ahead				**Three day ahead**				**Six day ahead**			
Yanco												
Extreme	0	0	0	0	0	0	0	0	0	0	0	0
High	0	0	0	0	0	0	0	0	0	0	0	0
Medium	0	0	0	0	0	0	0	0	0.7	0	0	0
Low	100	0	0	0	100	0	0	0	99.3	0	0	0
	Low	Medium	High	Extreme	Low	Medium	High	Extreme	Low	Medium	High	Extreme
Katanning												
Extreme	0	0	0	0	0	0	0	0	0	0	0	0
High	0	0	0	0	0	0	0	0	0	0	0	0
Medium	0	0	0	0	0	0	0	0	0	0	0	0
Low	100	0	0	0	100	0	0	0	100	0	0	0
	Low	Medium	High	Extreme	Low	Medium	High	Extreme	Low	Medium	High	Extreme
Charleton												
Extreme	0	0	0	0	4.9	0	0	0	2.8	0	0	0
High	0	0	0	0	0	0	0	0	0	0	0	0
Medium	0	0	0	0	0	0	0	0	0	0	0	0
Low	100	0	0	0	95.1	0	0	0	97.2	0	0	0
	Low	Medium	High	Extreme	Low	Medium	High	Extreme	Low	Medium	High	Extreme

Contingency tables of forecast vs observed AHLU for a HLI cut-off of 89												
	One day ahead				**Three day ahead**				**Six day ahead**			
Clare												
Extreme	0	0	0	0	0	0	0	0	0	0	0	0
High	0	0	0	0	0	0	0	0	0	0	0	0
Medium	0	0	0	0	0	0	0	0	0.7	0	0	0
Low	100	0	0	0	100	0	0	0	99.3	0	0	0
	Low	Medium	High	Extreme	Low	Medium	High	Extreme	Low	Medium	High	Extreme
Amberley												
Extreme	0	0	0	0	0	0	0	0	0	0	0	0
High	0.7	0.7	0	0	4.2	0	0	0	1.4	0.7	0	0
Medium	4.9	3.5	0	0	3.5	2.8	0	0	4.9	0	0	0
Low	89.4	0.7	0	0	87.3	2.1	0	0	88.7	4.2	0	0
	Low	Medium	High	Extreme	Low	Medium	High	Extreme	Low	Medium	High	Extreme
Emerald												
Extreme	0	0	0	0	0.7	0	0	0	1.4	0	0	0
High	0.7	0.7	0	0	2.8	0.7	0	0	4.9	0.7	0	0
Medium	8.5	0	0	0	6.3	0	0	0	5.6	0	0	0
Low	90.1	0	0	0	89.4	0	0	0	87.3	0	0	0
	Low	Medium	High	Extreme	Low	Medium	High	Extreme	Low	Medium	High	Extreme

Contingency tables of forecast vs observed AHLU for a HLI cut-off of 89												
	One day ahead				**Three day ahead**				**Six day ahead**			
Miles												
Extreme	0	0	0	0	0	0	0	0	0	0	0	0
High	0	0.7	1.4	0	0.7	0.7	0	0	0	0	0	0
Medium	4.2	2.1	0	0	3.5	0	1.4	0	3.5	0.7	0	0
Low	89.4	2.1	0	0	89.4	4.2	0	0	90.1	4.2	1.4	0
	Low	Medium	High	Extreme	Low	Medium	High	Extreme	Low	Medium	High	Extreme
Oakey												
Extreme	0	0	0	0	0	0	0	0	0	0	0	0
High	0	0	0	0	0	0	0	0	0	0	0	0
Medium	0	0	0	0	0	0	0	0	0	0	0	0
Low	100	0	0	0	100	0	0	0	100	0	0	0
	Low	Medium	High	Extreme	Low	Medium	High	Extreme	Low	Medium	High	Extreme
Roma												
Extreme	0	0	0	0	0	0	0	0	0	0	0	0
High	0	0	0	0	0	0	0	0	0	0	0	0
Medium	1.4	0.7	0	0	2.8	0	0	0	2.1	0	0	0
Low	97.9	0	0	0	96.5	0.7	0	0	97.2	0.7	0	0
	Low	Medium	High	Extreme	Low	Medium	High	Extreme	Low	Medium	High	Extreme

Contingency tables of forecast vs observed AHLU for a HLI cut-off of 89												
	One day ahead				**Three day ahead**				**Six day ahead**			
Warwick												
Extreme	0	0	0	0	0	0	0	0	0	0	0	0
High	0.7	0	0	0	0	0	0	0	0	0	0	0
Medium	2.1	0	0	0	0.7	0	0	0	0.7	0	0	0
Low	97.2	0	0	0	99.3	0	0	0	99.3	0	0	0
	Low	Medium	High	Extreme	Low	Medium	High	Extreme	Low	Medium	High	Extreme

Table C3: HLI cut-off of 92

Contingency tables of forecast vs observed AHLU for a HLI cutoff of 92												
	One day ahead				**Three day ahead**				**Six day ahead**			
Albury												
Extreme	0	0	0	0	0	0	0	0	0	0	0	0
High	0	0	0	0	0	0	0	0	0	0	0	0
Medium	0	0	0	0	0	0	0	0	0	0	0	0
Low	100	0	0	0	100	0	0	0	100	0	0	0
	Low	Medium	High	Extreme	Low	Medium	High	Extreme	Low	Medium	High	Extreme
Armidale												
Extreme	0	0	0	0	0	0	0	0	0	0	0	0
High	0	0	0	0	0	0	0	0	0	0	0	0
Medium	0	0	0	0	0	0	0	0	0	0	0	0
Low	100	0	0	0	100	0	0	0	100	0	0	0
	Low	Medium	High	Extreme	Low	Medium	High	Extreme	Low	Medium	High	Extreme
Griffith												
Extreme	0	0	0	0	0	0	0	0	0	0	0	0
High	0	0	0	0	0	0	0	0	0	0	0	0
Medium	0	0	0	0	0	0	0	0	0	0	0	0
Low	100	0	0	0	100	0	0	0	100	0	0	0
	Low	Medium	High	Extreme	Low	Medium	High	Extreme	Low	Medium	High	Extreme

Contingency tables of forecast vs observed AHLU for a HLI cutoff of 92												
	One day ahead				Three day ahead				Six day ahead			
Hay												
Extreme	0	0	0	0	0	0	0	0	0	0	0	0
High	0	0	0	0	0	0	0	0	0	0	0	0
Medium	0	0	0	0	0	0	0	0	0	0	0	0
Low	100	0	0	0	100	0	0	0	100	0	0	0
	Low	Medium	High	Extreme	Low	Medium	High	Extreme	Low	Medium	High	Extreme
Moree												
Extreme	0	0	0	0	0	0	0	0	0	0	0	0
High	0	0	0	0	0	0	0	0	0	0	0	0
Medium	0	0	0	0	0	0	0	0	0	0	0	0
Low	100	0	0	0	100	0	0	0	100	0	0	0
	Low	Medium	High	Extreme	Low	Medium	High	Extreme	Low	Medium	High	Extreme
Tamworth												
Extreme	0	0	0	0	0	0	0	0	0	0	0	0
High	0	0	0	0	0	0	0	0	0	0	0	0
Medium	0	0	0	0	0	0	0	0	0	0	0	0
Low	100	0	0	0	100	0	0	0	100	0	0	0
	Low	Medium	High	Extreme	Low	Medium	High	Extreme	Low	Medium	High	Extreme

Contingency tables of forecast vs observed AHLU for a HLI cutoff of 92												
	One day ahead				**Three day ahead**				**Six day ahead**			
Yanco												
Extreme	0	0	0	0	0	0	0	0	0	0	0	0
High	0	0	0	0	0	0	0	0	0	0	0	0
Medium	0	0	0	0	0	0	0	0	0	0	0	0
Low	100	0	0	0	100	0	0	0	100	0	0	0
	Low	Medium	High	Extreme	Low	Medium	High	Extreme	Low	Medium	High	Extreme
Katanning												
Extreme	0	0	0	0	0	0	0	0	0	0	0	0
High	0	0	0	0	0	0	0	0	0	0	0	0
Medium	0	0	0	0	0	0	0	0	0	0	0	0
Low	100	0	0	0	100	0	0	0	100	0	0	0
	Low	Medium	High	Extreme	Low	Medium	High	Extreme	Low	Medium	High	Extreme
Charleton												
Extreme	0	0	0	0	4.2	0	0	0	2.1	0	0	0
High	0	0	0	0	0.7	0	0	0	0.7	0	0	0
Medium	0	0	0	0	0	0	0	0	0	0	0	0
Low	100	0	0	0	95.1	0	0	0	97.2	0	0	0
	Low	Medium	High	Extreme	Low	Medium	High	Extreme	Low	Medium	High	Extreme

Contingency tables of forecast vs observed AHLU for a HLI cutoff of 92												
	One day ahead				**Three day ahead**				**Six day ahead**			
Clare												
Extreme	0	0	0	0	0	0	0	0	0	0	0	0
High	0	0	0	0	0	0	0	0	0	0	0	0
Medium	0	0	0	0	0	0	0	0	0	0	0	0
Low	100	0	0	0	100	0	0	0	100	0	0	0
	Low	Medium	High	Extreme	Low	Medium	High	Extreme	Low	Medium	High	Extreme
Amberley												
Extreme	0	0	0	0	0	0	0	0	0	0	0	0
High	0	0	0	0	0	0	0	0	0	0	0	0
Medium	1.4	0	0	0	1.4	0	0	0	1.4	0	0	0
Low	98.6	0	0	0	98.6	0	0	0	98.6	0	0	0
	Low	Medium	High	Extreme	Low	Medium	High	Extreme	Low	Medium	High	Extreme
Emerald												
Extreme	0	0	0	0	0	0	0	0	0	0	0	0
High	0	0	0	0	0.7	0	0	0	2.1	0	0	0
Medium	0.7	0.7	0	0	2.8	0.7	0	0	0.7	0	0	0
Low	98.6	0	0	0	95.8	0	0	0	96.5	0.7	0	0
	Low	Medium	High	Extreme	Low	Medium	High	Extreme	Low	Medium	High	Extreme

Contingency tables of forecast vs observed AHLU for a HLI cutoff of 92												
	One day ahead				**Three day ahead**				**Six day ahead**			
Miles												
Extreme	0	0	0	0	0	0	0	0	0	0	0	0
High	0	0	0	0	0	0	0	0	0	0	0	0
Medium	0.7	0	1.4	0	0	0	0	0	0	0	0	0
Low	95.8	2.1	0	0	96.5	2.1	1.4	0	96.5	2.1	1.4	0
	Low	Medium	High	Extreme	Low	Medium	High	Extreme	Low	Medium	High	Extreme
Oakey												
Extreme	0	0	0	0	0	0	0	0	0	0	0	0
High	0	0	0	0	0	0	0	0	0	0	0	0
Medium	0	0	0	0	0	0	0	0	0	0	0	0
Low	100	0	0	0	100	0	0	0	100	0	0	0
	Low	Medium	High	Extreme	Low	Medium	High	Extreme	Low	Medium	High	Extreme
Roma												
Extreme	0	0	0	0	0	0	0	0	0	0	0	0
High	0	0	0	0	0	0	0	0	0	0	0	0
Medium	0	0	0	0	0.7	0	0	0	0	0	0	0
Low	100	0	0	0	99.3	0	0	0	100	0	0	0
	Low	Medium	High	Extreme	Low	Medium	High	Extreme	Low	Medium	High	Extreme

Contingency tables of forecast vs observed AHLU for a HLI cutoff of 92												
	One day ahead				Three day ahead				Six day ahead			
Warwick												
Extreme	0	0	0	0	0	0	0	0	0	0	0	0
High	0	0	0	0	0	0	0	0	0	0	0	0
Medium	0.7	0	0	0	0	0	0	0	0	0	0	0
Low	99.3	0	0	0	100	0	0	0	100	0	0	0
	Low	Medium	High	Extreme	Low	Medium	High	Extreme	Low	Medium	High	Extreme

Table C4: HLI cut-off of 95

Contingency tables of Forecast vs Observed AHLU for a HLI cut-off of 95												
	One day ahead				**Three day ahead**				**Six day ahead**			
Albury												
Extreme	0	0	0	0	0	0	0	0	0	0	0	0
High	0	0	0	0	0	0	0	0	0	0	0	0
Medium	0	0	0	0	0	0	0	0	0	0	0	0
Low	100	0	0	0	100	0	0	0	100	0	0	0
	Low	Medium	High	Extreme	Low	Medium	High	Extreme	Low	Medium	High	Extreme
Armidale												
Extreme	0	0	0	0	0	0	0	0	0	0	0	0
High	0	0	0	0	0	0	0	0	0	0	0	0
Medium	0	0	0	0	0	0	0	0	0	0	0	0
Low	100	0	0	0	100	0	0	0	100	0	0	0
	Low	Medium	High	Extreme	Low	Medium	High	Extreme	Low	Medium	High	Extreme
Griffith												
Extreme	0	0	0	0	0	0	0	0	0	0	0	0
High	0	0	0	0	0	0	0	0	0	0	0	0
Medium	0	0	0	0	0	0	0	0	0	0	0	0
Low	100	0	0	0	100	0	0	0	100	0	0	0
	Low	Medium	High	Extreme	Low	Medium	High	Extreme	Low	Medium	High	Extreme

Contingency tables of Forecast vs Observed AHLU for a HLI cut-off of 95												
	One day ahead				**Three day ahead**				**Six day ahead**			
Hay												
Extreme	0	0	0	0	0	0	0	0	0	0	0	0
High	0	0	0	0	0	0	0	0	0	0	0	0
Medium	0	0	0	0	0	0	0	0	0	0	0	0
Low	100	0	0	0	100	0	0	0	100	0	0	0
	Low	Medium	High	Extreme	Low	Medium	High	Extreme	Low	Medium	High	Extreme
Moree												
Extreme	0	0	0	0	0	0	0	0	0	0	0	0
High	0	0	0	0	0	0	0	0	0	0	0	0
Medium	0	0	0	0	0	0	0	0	0	0	0	0
Low	100	0	0	0	100	0	0	0	100	0	0	0
	Low	Medium	High	Extreme	Low	Medium	High	Extreme	Low	Medium	High	Extreme
Tamworth												
Extreme	0	0	0	0	0	0	0	0	0	0	0	0
High	0	0	0	0	0	0	0	0	0	0	0	0
Medium	0	0	0	0	0	0	0	0	0	0	0	0
Low	100	0	0	0	100	0	0	0	100	0	0	0
	Low	Medium	High	Extreme	Low	Medium	High	Extreme	Low	Medium	High	Extreme

Contingency tables of Forecast vs Observed AHLU for a HLI cut-off of 95												
	One day ahead				Three day ahead				Six day ahead			
Yanco												
Extreme	0	0	0	0	0	0	0	0	0	0	0	0
High	0	0	0	0	0	0	0	0	0	0	0	0
Medium	0	0	0	0	0	0	0	0	0	0	0	0
Low	100	0	0	0	100	0	0	0	100	0	0	0
	Low	Medium	High	Extreme	Low	Medium	High	Extreme	Low	Medium	High	Extreme
Katanning												
Extreme	0	0	0	0	0	0	0	0	0	0	0	0
High	0	0	0	0	0	0	0	0	0	0	0	0
Medium	0	0	0	0	0	0	0	0	0	0	0	0
Low	100	0	0	0	100	0	0	0	100	0	0	0
	Low	Medium	High	Extreme	Low	Medium	High	Extreme	Low	Medium	High	Extreme
Charleton												
Extreme	0	0	0	0	3.5	0	0	0	2.1	0	0	0
High	0	0	0	0	0.7	0	0	0	0	0	0	0
Medium	0	0	0	0	0	0	0	0	0	0	0	0
Low	100	0	0	0	95.8	0	0	0	97.9	0	0	0
	Low	Medium	High	Extreme	Low	Medium	High	Extreme	Low	Medium	High	Extreme

Contingency tables of Forecast vs Observed AHLU for a HLI cut-off of 95												
	One day ahead				**Three day ahead**				**Six day ahead**			
Clare												
Extreme	0	0	0	0	0	0	0	0	0	0	0	0
High	0	0	0	0	0	0	0	0	0	0	0	0
Medium	0	0	0	0	0	0	0	0	0	0	0	0
Low	100	0	0	0	100	0	0	0	100	0	0	0
	Low	Medium	High	Extreme	Low	Medium	High	Extreme	Low	Medium	High	Extreme
Amberley												
Extreme	0	0	0	0	0	0	0	0	0	0	0	0
High	0	0	0	0	0	0	0	0	0	0	0	0
Medium	0.7	0	0	0	0	0	0	0	0	0	0	0
Low	99.3	0	0	0	100	0	0	0	100	0	0	0
	Low	Medium	High	Extreme	Low	Medium	High	Extreme	Low	Medium	High	Extreme
Emerald												
Extreme	0	0	0	0	0	0	0	0	0	0	0	0
High	0	0	0	0	0	0	0	0	0	0	0	0
Medium	0	0	0	0	0.7	0	0	0	2.1	0	0	0
Low	100	0	0	0	99.3	0	0	0	97.9	0	0	0
	Low	Medium	High	Extreme	Low	Medium	High	Extreme	Low	Medium	High	Extreme

Contingency tables of Forecast vs Observed AHLU for a HLI cut-off of 95												
	One day ahead				**Three day ahead**				**Six day ahead**			
Miles												
Extreme	0	0	0	0	0	0	0	0	0	0	0	0
High	0	0	0	0	0	0	0	0	0	0	0	0
Medium	0	0.7	0.7	0	0	0	0	0	0	0	0	0
Low	97.9	0.7	0	0	97.9	1.4	0.7	0	97.9	1.4	0.7	0
	Low	Medium	High	Extreme	Low	Medium	High	Extreme	Low	Medium	High	Extreme
Oakey												
Extreme	0	0	0	0	0	0	0	0	0	0	0	0
High	0	0	0	0	0	0	0	0	0	0	0	0
Medium	0	0	0	0	0	0	0	0	0	0	0	0
Low	100	0	0	0	100	0	0	0	100	0	0	0
	Low	Medium	High	Extreme	Low	Medium	High	Extreme	Low	Medium	High	Extreme
Roma												
Extreme	0	0	0	0	0	0	0	0	0	0	0	0
High	0	0	0	0	0	0	0	0	0	0	0	0
Medium	0	0	0	0	0	0	0	0	0	0	0	0
Low	100	0	0	0	100	0	0	0	100	0	0	0
	Low	Medium	High	Extreme	Low	Medium	High	Extreme	Low	Medium	High	Extreme

Contingency tables of Forecast vs Observed AHLU for a HLI cut-off of 95												
One day ahead					**Three day ahead**				**Six day ahead**			
Warwick												
Extreme	0	0	0	0	0	0	0	0	0	0	0	0
High	0	0	0	0	0	0	0	0	0	0	0	0
Medium	0	0	0	0	0	0	0	0	0	0	0	0
Low	100	0	0	0	100	0	0	0	100	0	0	0
	Low	Medium	High	Extreme	Low	Medium	High	Extreme	Low	Medium	High	Extreme