final report

Project code: FLOT.334

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Date published: November 2011

ISBN: 9781741917154

PUBLISHED BY
Meat & Livestock Australia Limited
Locked Bag 991
NORTH SYDNEY NSW 2059

Cattle Heat Load Forecast Service for 2005/2006 Summer

Meat & Livestock Australia acknowledges the matching funds provided by the Australian Government to support the research and development detailed in this publication.

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ABSTRACT

A weather forecasting system was developed to assist in warning operators of cattle feedlots 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 (BoM) automatic weather stations (AWS) are located.

The forecasts were made over the period 1 October 2005 to 30 March 2006 at 17 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) and ultimately the Accumulated Heat Load Unit (AHLU).

Forecasts for all 17 sites were posted daily onto a website (www.katestone.com.au/mla) for easy access to all feedlot operators.

There was good agreement between the forecast and observed temperature and dew point. The relative humidity was calculated from these parameters. Solar radiation was calculated analytically using the date, time of day and latitude of the site. The wind speed forecasting performance, however, was relatively poor.

Heat stress is divided into four risk categories: low, medium, high and extreme. The risk categories span AHLU values of 0 to greater than 100. The low risk category ranges from 0 to 20 AHLU, the higher risk categories extend over 30 and 50 AHLU. It is more important to predict the heat stress category well than the actual AHLU, therefore the forecasting performance is reasonably good. The forecasting system's performance at predicting the risk category has been found to be good. It is much more difficult to predict individual AHLU values and, consequently, the forecasting system performs relatively poorly in this regard.

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 for 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). 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), again in 2004-05 to include Charlton in Victoria and also to incorporate a revised HLI algorithm and the Accumulated Heat Load Unit (AHLU). In 2005, the service was again expanded to include the site at Cessnock, NSW. The present study includes the following 17 sites:

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

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.

(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 AWS are situated near significant populations or industrial regions and as such only 17 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. Cessnock and Charlton) 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.

- Transfer forecasts to a web site on a daily basis.

- 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

The main factors that affect the HLI (and AHLU) are temperature, relative humidity (obtained from the dew point) and wind speed. There was good agreement between the forecast temperature and dew point and the observed quantities, however, the wind speed forecasting performance was relatively poor.

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.

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 since 2001-02 and now includes seventeen sites around Australia with forecasts being conducted every day over the summer period. Also, for the 2005/2006 summer period, the MLA requested that the service commence before the start of summer in anticipation of high heat stress events. As a result, the service was provided over the period 1 October 2005 to 30 March 2006.

The study included the following sites:

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

Study definition and objectives

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 to be made for the period 1 October 2005 to 30 March 2006.
- 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 (BoM). These are the parameters from which many heat stress indices can be derived. It is also highly desirable to include rainfall and solar radiation parameters in any heat load 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 solar radiation used here is relatively minor and as such the resulting overestimation is 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 of 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 potentially 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.

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 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 HLI. 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. For discussion and details of 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 that 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 representing 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 (RelHum in %) 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:

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

Equation 3. Heat Load Index equations

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/m^2
BGT (Black Globe Temperature) stated in 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:

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

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 which ultimately rely on the accuracy of 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, in the case of low AHLU values, 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 or thresholds, 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 17 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 and each of these is further subdivided into 6 HLI threshold categories, resulting in excess of 300 pairs of data sets for each of these parameters.

In order to keep this report a reasonable length, discussion will be restricted to the general behaviour of the relevant parameters. Detailed summaries are presented in appendices. 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 statistical and line of best fit parameters describing the accuracy of the forecasting process. The overall tendency is for the forecast accuracy to decrease as the forecast horizon increases, as would be expected. 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 is a scatter plot of the one day ahead forecasts of HLI plotted against observed HLI for Amberley. There are several features in this graph which merit some comment.

Firstly, the sharp cutoff 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 increase. 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 85, representing night time and 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 or these result from using two different expressions for calculating the HLI, ie whether the BGT is above or below 25. The last explanation is discussed further in Appendix D where an alternative method for calculating the HLI is presented.

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 Amberley.

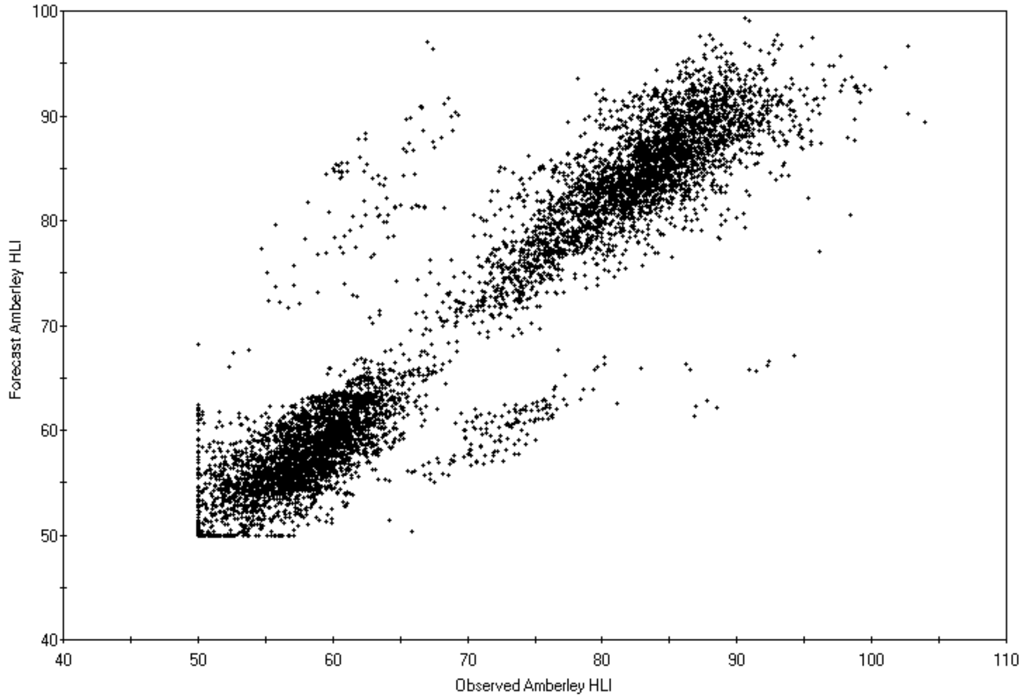

Figure 1: One day ahead forecast versus observed HLI for Amberley.

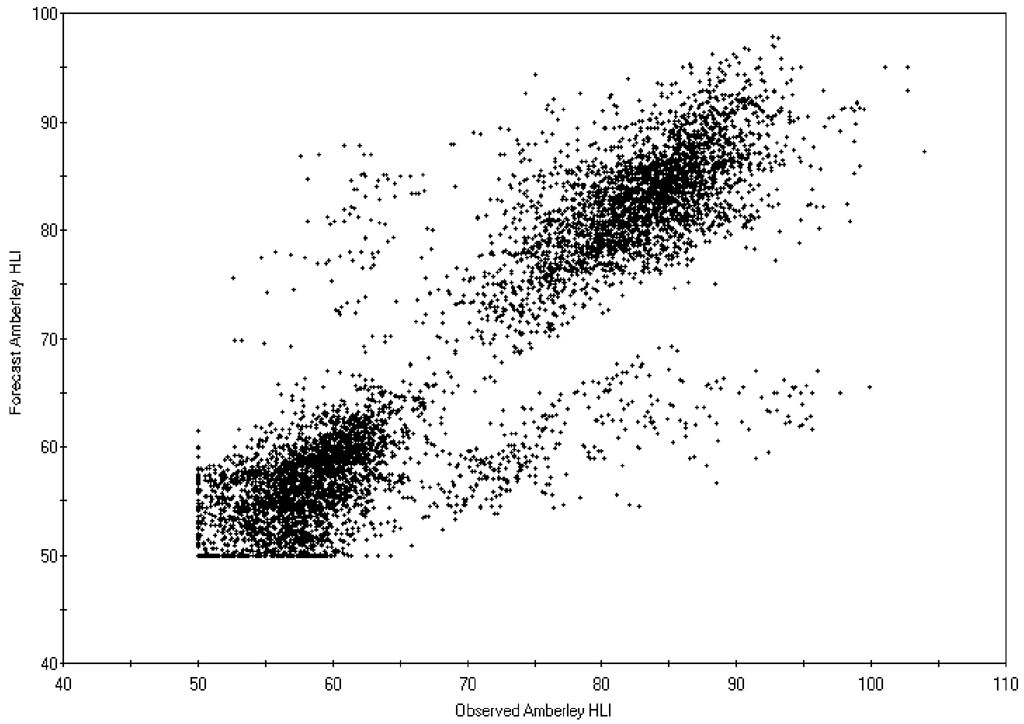

Figure 2: Three day ahead forecast versus observed HLI for Amberley.

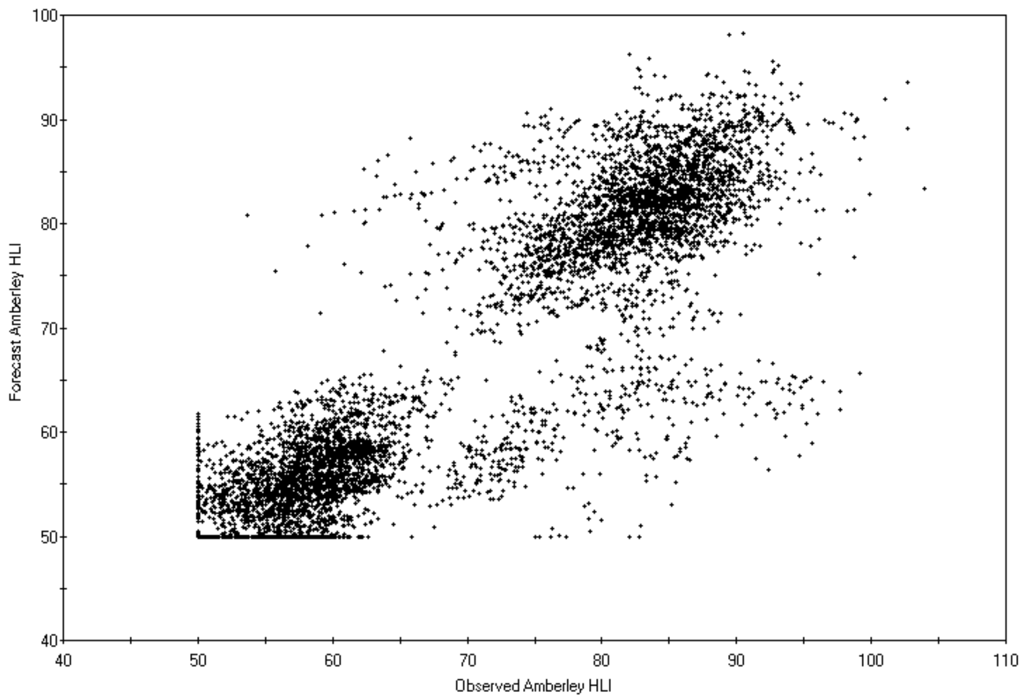

Figure 3: Six day ahead forecast versus observed HLI for Amberley.

Note that the features discussed above are still present; also the correlation deteriorates noticeably for the six day ahead forecasts.

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

Behaviour of HLI and AHLU

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 – i.e. the performance of the forecasting algorithm is poor.

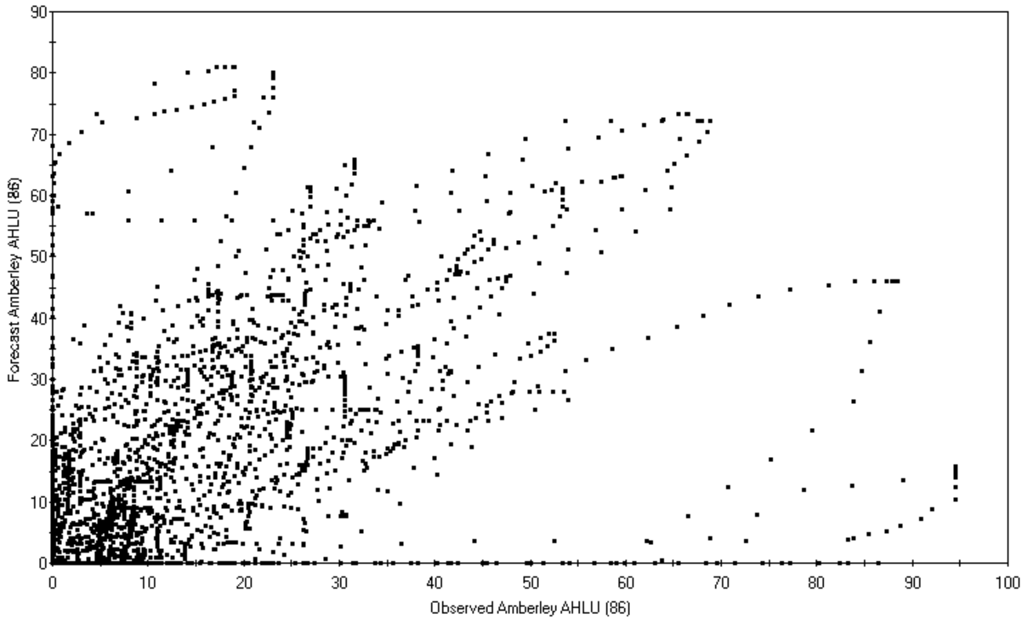

Figure 4: One day ahead forecast versus observed AHLU (half-hour average data) for Amberley using a HLI value of 86 for the Thermo-Neutral zone upper limit.

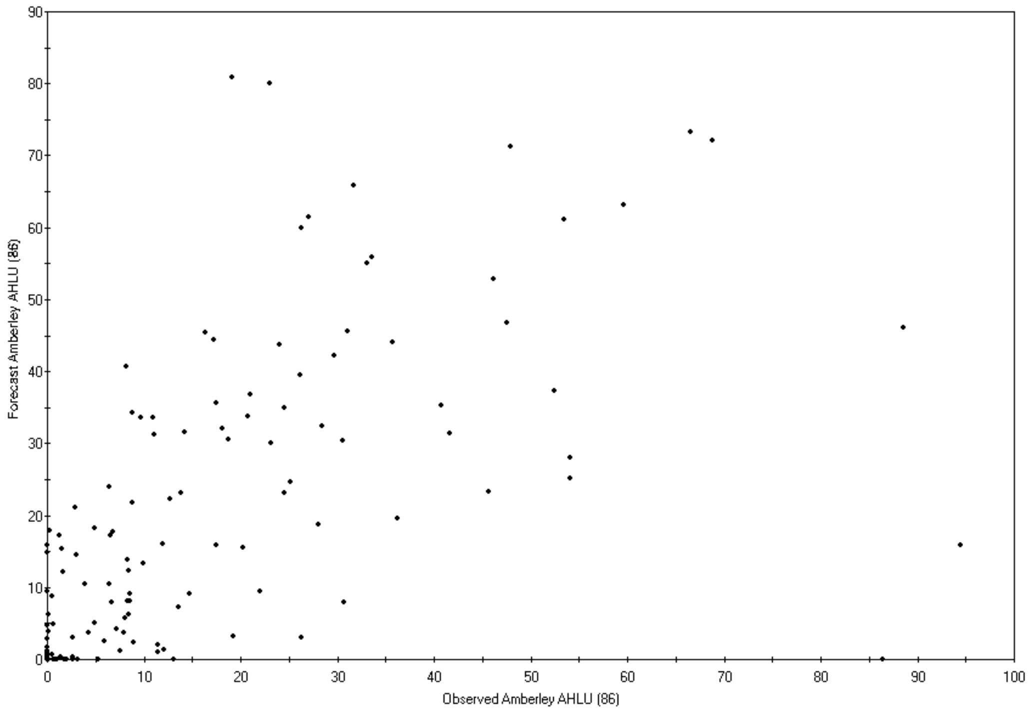

Figure 5: One day ahead forecast versus observed AHLU (daily maximum) for Amberley using a HLI value of 86 for the Thermo-Neutral zone upper limit.

Further insight into the causes of the poor performance in forecasting the AHLU can be seen in Figure 6 which shows the time series of observed and one day ahead forecasts of HLI and AHLU for Amberley. The two horizontal lines are the upper and lower Thermo-Neutral zone limits and the dotted traces are the observed quantities. The HLI traces are uppermost.

The HLI traces show the same general behaviour, however large discrepancies in AHLU can be seen at the events labelled “A” and in the vicinity of “B”. Event “C” is one of the instances where performance is good.

There are two mechanisms that give rise to the poor performance, one being the performance in forecasting the HLI as depicted in Figure 1. The poor correlation in Figure 4 can also be partly attributed to the method used to calculate the AHLU. For example, if the observed HLI is slightly above the Thermo-Neutral zone upper limit and the forecast is slightly below, then observed AHLU will increase whereas the forecast AHLU will not, even though the HLI behaviour is comparable in both cases. This is the case for the events labelled “A” in the figure. Also, because of the cumulative nature of the AHLU, any errors in AHLU from previous calculations will compound the effect. This effect is partly responsible for the discrepancies at the event labelled “B” in the figure.

Finally, 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.

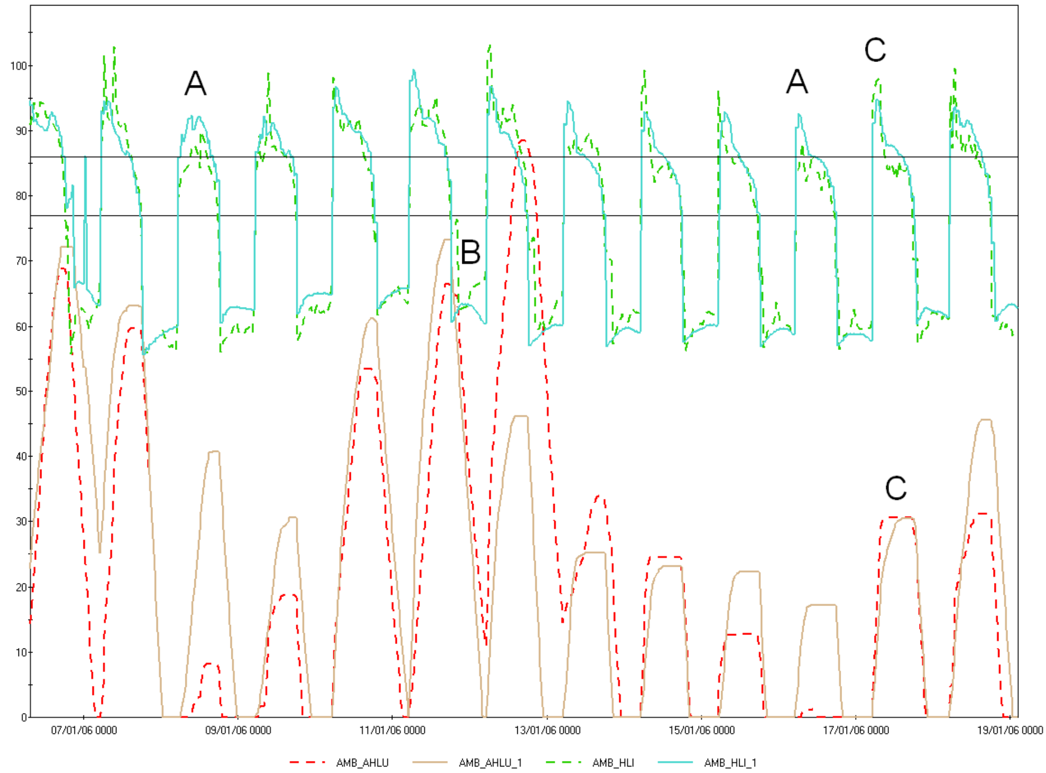

Figure 6: Time series of observed and one day ahead forecasts of HLI and AHLU using a HLI value of 86 for the Thermo-Neutral zone upper limit for Amberley.

Forecasting performance for Meteorological variables

The meteorological parameters used in this project are derived from BoM forecasts and BoM observations at weather stations. These data are used to train propriety models to produce site specific forecasts. Clearly the accuracy of any forecast is dependent on the accuracy of the input data – in this case, BoM forecasts.

Figures 7, 8 and 9 show time series of observed and one day ahead forecasts of temperature, relative humidity and wind speed for Amberley. There results are typical of forecasts obtained for the other sites. It is evident that the gross behaviour is modelled reasonably well (except for the wind speed – where there appears to be a systematic error), however, it is not clear to what degree the discrepancies can be attributed to errors in the supplied BoM forecasts. It is envisaged that a substantial effort would be required to resolve this issue.

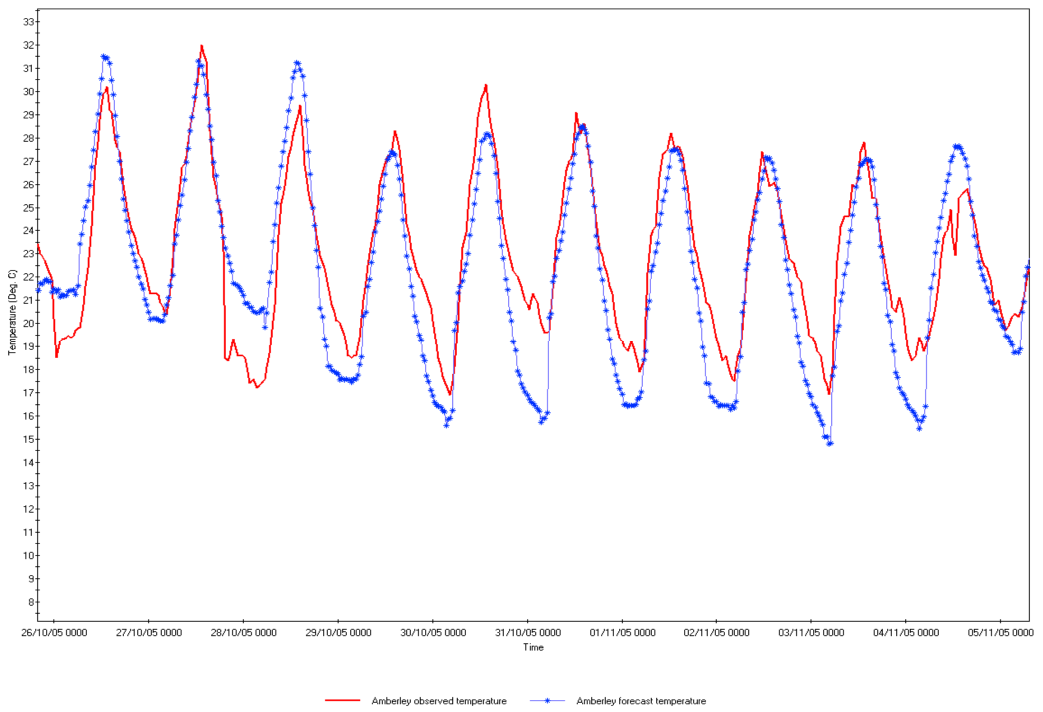

Figure 7: Time series of observed (solid line) and one day ahead forecast of temperature (dotted line) for Amberley.

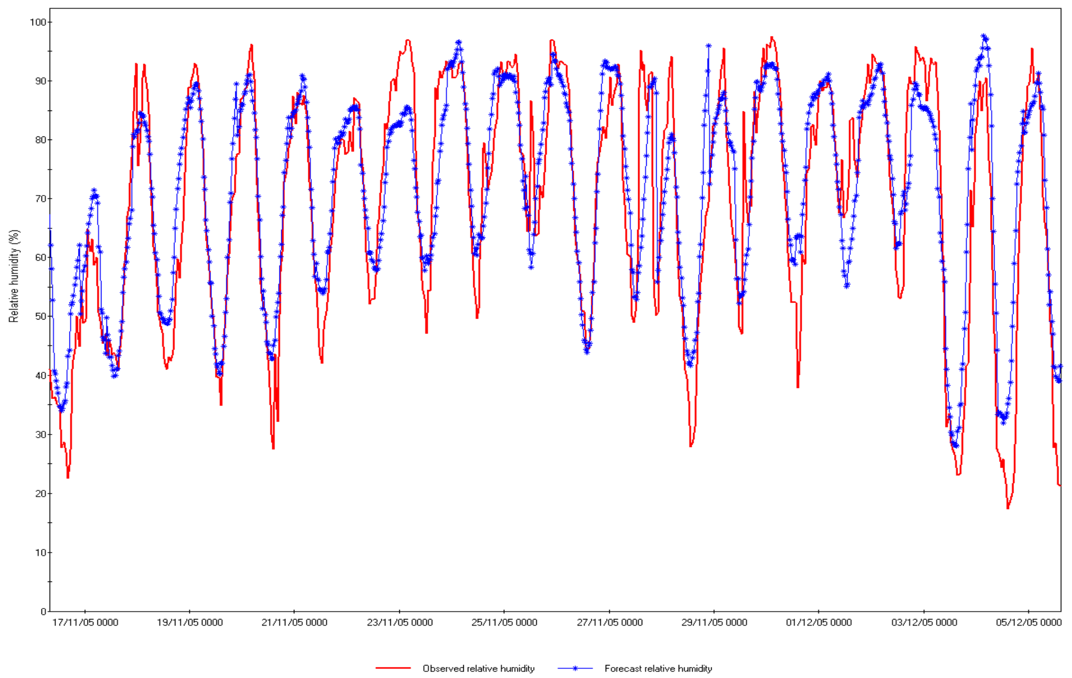

Figure 8: Time series of observed (solid line) and one day ahead forecast of relative humidity (dotted line) for Amberley.

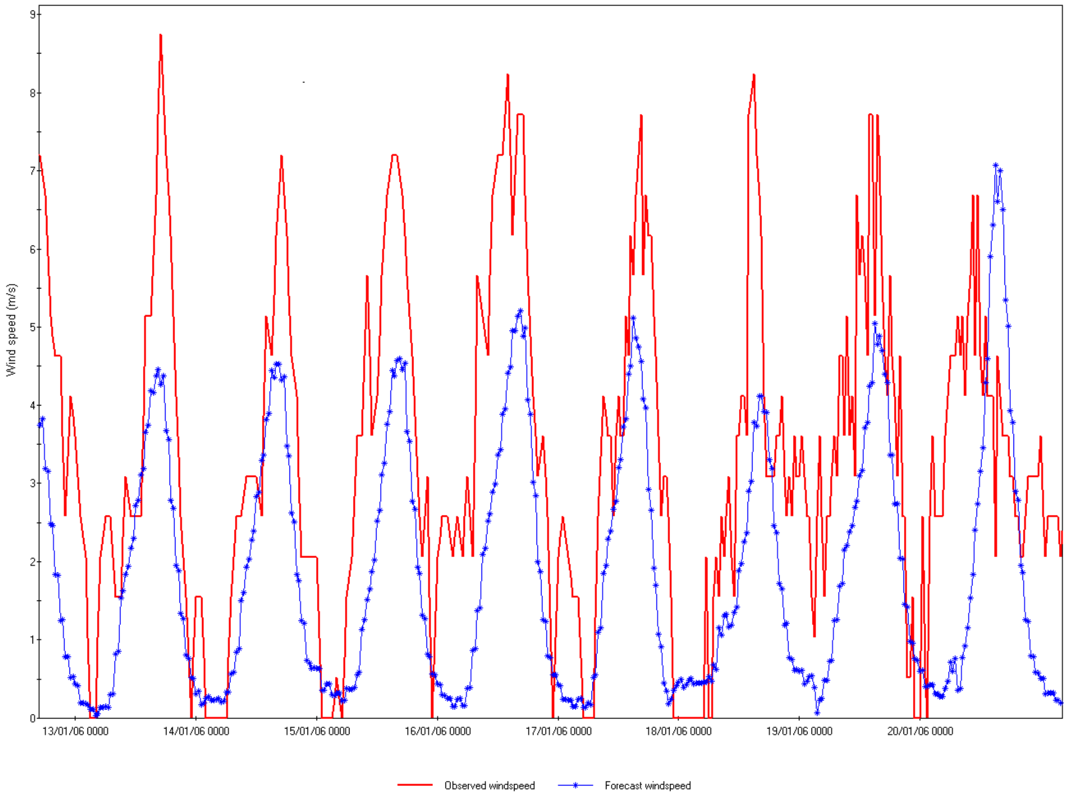

Figure 9: Time series of observed (solid line) and one day ahead forecast of wind speed (dotted line) for Amberley.

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, …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. Also, the project would benefit from investigations into alternative methods for calculating the AHLU.

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 the 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 extended summer period period 1 October 2005 to 30 March 2006. 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 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.

Two factors were found to contribute to the poor AHLU forecasts these were the performance in forecasting the HLI and the method for determining the AHLU, with the method for calculating the AHLU being the major factor.

Finally, although the forecast AHLU values were generally higher than the values obtained from observations, the performance in predicting the AHLU *categories* is good and is more relevant as far as feedlot operations are concerned than predicting the actual AHLU *values*.

References

EA Systems (2004), “FLOT. 327 – Development of a Heat Load Risk Assessment Process for the Australian feedlot industry”.

Gaughan, J. Goopy J. and Spark J (2002), “Excessive Heat Load Index for Feedlot Cattle”, University of Queensland.

Katestone Scientific (2002), “FLOT. 313 – Development and trial operation of a weather forecasting service for excessive heat load events for the Australian feedlot industry.”

Leonard, M.J., Spiers, D.E., and G.L. Hahn, “Adaptation of feedlot cattle to repeated sinusoidal heat challenge”, Livestock Environment VI – Proceedings of the Sixth International Symposium Galt House Hotel Louisville, Kentucky, May 21-23, 2001, Published by The Society for engineering in agriculture, food and biological systems.

Oke TR (1987), “Boundary Layer Climates”, Second Edition, Routledge.

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 Bureau of Meteorology (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.

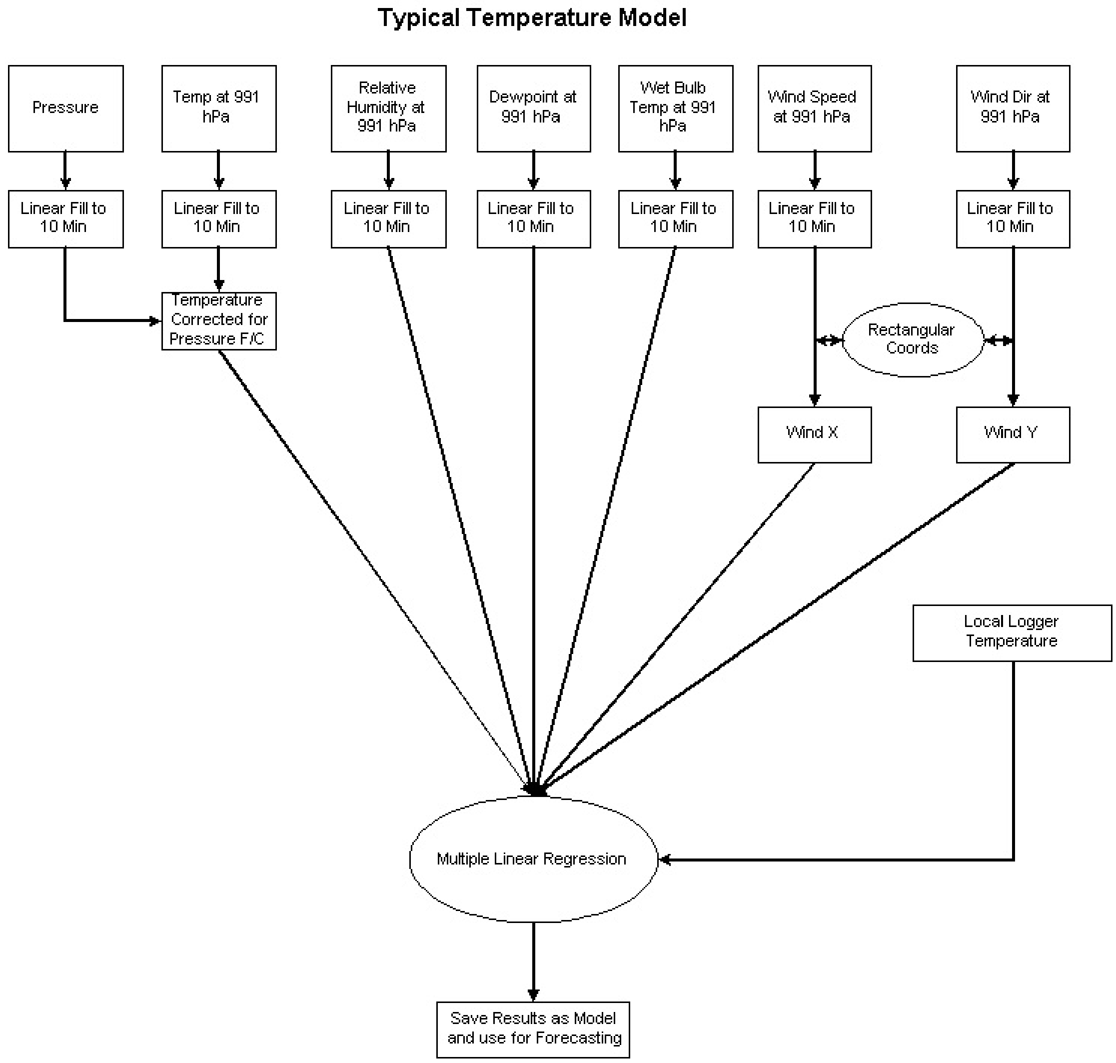

Figure A1: Example of process of using LAPS/GASP data (e.g. 991 hpa parameters) in downscaling to give a surface temperature forecast

Table A1: Mean Absolute Error for Sydney and Brisbane forecasts

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

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 an indication 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 slightly decreases as the forecast horizon increases.

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

Cessnock, 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 the period 1 October 2005 to 30 March 2006

Site	Slope	Intercept	Pearson	RMSE	IOA	Bias	Count
One day ahead forecasts							
Albury	0.96	4.25	0.88	5.46	0.93	1.24	4903
Amberley	1.01	0.16	0.95	4.49	0.97	0.68	6901
Armidale	0.92	6.19	0.89	5.09	0.94	1.10	4715
Cessnock	0.99	2.82	0.93	5.41	0.96	2.01	2866
Charlton	0.94	3.94	0.87	4.99	0.93	-0.18	4060
Clare	0.94	4.48	0.86	5.21	0.93	0.45	3931
Emerald	1.02	-1.82	0.94	4.40	0.97	-0.29	7253
Griffith	0.92	4.98	0.91	3.98	0.95	-0.60	4693
Hay	0.90	6.48	0.89	4.53	0.94	-0.56	4165
Katanning	0.81	11.80	0.80	5.60	0.89	-0.02	3229
Miles	0.87	8.54	0.89	6.42	0.94	-0.58	6767
Moree	0.97	3.59	0.91	5.10	0.95	1.18	6013
Oakey	0.97	2.57	0.95	4.00	0.97	0.26	6258
Roma	0.95	4.63	0.91	5.03	0.95	1.19	6505
Tamworth	0.97	3.46	0.92	4.76	0.96	1.07	5458
Warwick	0.92	5.25	0.94	4.80	0.97	-0.04	6708
Yanco	0.94	4.22	0.91	3.99	0.96	0.07	4794
Three day ahead forecasts							
Albury	0.93	7.69	0.84	7.11	0.9	2.91	4796
Amberley	0.94	3.04	0.90	6.00	0.95	-1.31	6623
Armidale	0.90	11.81	0.83	8.22	0.87	5.23	4787
Cessnock	0.94	7.89	0.91	6.85	0.93	4.04	2765
Charlton	0.90	8.34	0.75	7.54	0.86	1.42	3990
Clare	0.94	5.65	0.82	6.68	0.89	1.94	3896
Emerald	0.97	-0.51	0.91	6.09	0.94	-2.42	7007

Site	Slope	Intercept	Pearson	RMSE	IOA	Bias	Count
Griffith	0.84	11.26	0.85	5.13	0.92	0.26	4538
Hay	0.81	13.78	0.83	5.64	0.91	0.50	4157
Katanning	0.81	13.58	0.73	7.16	0.85	1.85	3352
Miles	0.83	13.70	0.88	6.82	0.93	1.20	6716
Moree	0.89	12.10	0.87	7.19	0.91	4.06	6018
Oakey	0.93	5.03	0.93	4.71	0.96	0.46	6327
Roma	0.96	3.53	0.90	5.48	0.95	0.80	6399
Tamworth	0.94	8.31	0.89	7.06	0.91	4.36	5459
Warwick	0.89	8.18	0.91	5.70	0.95	0.57	6630
Yanco	0.88	10.14	0.84	5.84	0.91	1.89	4693
Six day ahead forecasts							
Albury	0.84	13.93	0.74	8.48	0.85	2.74	4272
Amberley	0.89	4.99	0.87	7.21	0.92	-2.86	5767
Armidale	0.82	17.1	0.77	9.04	0.83	5.10	4308
Cessnock	0.93	9.25	0.90	7.21	0.92	4.13	2297
Charlton	0.76	17.39	0.67	8.15	0.82	0.81	3653
Clare	0.79	14.15	0.69	8.21	0.82	0.21	3617
Emerald	0.94	1.08	0.88	6.91	0.92	-3.31	6230
Griffith	0.71	20.91	0.72	6.79	0.85	0.02	4018
Hay	0.69	22.49	0.71	7.08	0.84	0.43	3650
Katanning	0.77	18.01	0.68	8.40	0.80	3.22	3037
Miles	0.80	15.08	0.85	7.38	0.92	0.13	6031
Moree	0.85	14.38	0.83	7.80	0.89	3.96	5394
Oakey	0.89	6.97	0.90	5.68	0.95	-0.65	5626
Roma	0.93	5.39	0.86	6.28	0.93	0.53	5713
Tamworth	0.87	13.94	0.82	8.34	0.87	4.56	4796
Warwick	0.84	10.90	0.87	6.88	0.93	-0.32	5873

Site	Slope	Intercept	Pearson	RMSE	IOA	Bias	Count
Yanco	0.77	17.95	0.73	7.14	0.85	1.60	4114

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. The AHLU categories are defined in the following table:

Table C1: Table of AHLU values for the four categories.

AHLU	**Heat stress category**
0-20	Low risk
20-50	Medium risk
50-100	High risk
Over 100	Extreme risk

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 generally quite good.
- There is a tendency to over predict and the 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 C2: Contingency tables of forecast vs observed daily maximum AHLU using an upper HLI threshold of 86

	One day ahead				Three day ahead				Six day ahead			
Albury												
Extreme	0	0	0	0	0.5	0.5	0	0	0.5	0.5	0	0
High	1.1	0.5	0	0	4.4	0	0	0	3.8	0	0	0
Medium	6	0	0	0	2.2	0	0	0	4.4	0	0	0
Low	92.3	0	0	0	92.3	0	0	0	90.7	0	0	0
	Low	Medium	High	Extreme	Low	Medium	High	Extreme	Low	Medium	High	Extreme
Amberley												
Extreme	0	0	0	0	0	0	0.5	0	0	0	0	0
High	0.5	4.9	2.2	0	0.5	2.2	1.6	0	0.5	0.5	1.1	0
Medium	11.5	7.7	0.5	0	3.3	3.3	0	0	4.4	1.1	1.6	0
Low	70.3	2.2	0	0	79.1	8.8	0.5	0	78	11.5	1.1	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	1.1	0	0	0	0	0	0	0
Low	100	0	0	0	98.9	0	0	0	100	0	0	0
	Low	Medium	High	Extreme	Low	Medium	High	Extreme	Low	Medium	High	Extreme
Cessnock												
Extreme	0	0	0	0	0.5	0	0	0	0	0	0	0
High	1.6	0.5	0.5	0	1.6	1.1	0.5	0	0.5	0	0	0
Medium	1.6	0.5	0	0	6	0	0	0	4.9	1.1	0.5	0
Low	94.5	0.5	0	0	89.6	0.5	0	0	92.3	0.5	0	0
	Low	Medium	High	Extreme	Low	Medium	High	Extreme	Low	Medium	High	Extreme
Charlton												

	One day ahead					**Three day ahead**					**Six day ahead**			
Extreme	0	0	0	0		2.2	1.1	0	0		2.2	0.5	0	0
High	0	0.5	0	0		1.1	0.5	0	0		0.5	1.6	0	0
Medium	0.5	1.1	0	0		4.4	0	0	0		1.6	0	0	0
Low	97.8	0	0	0		90.7	0	0	0		93.4	0	0	0
	Low	Medium	High	Extreme		Low	Medium	High	Extreme		Low	Medium	High	Extreme
Clare														
Extreme	0	0	0	0		0	0	0	0		1.1	0	0	0
High	0	0	0	0		1.6	0	0	0		2.2	0	0	0
Medium	2.2	0	0	0		5.5	0	0	0		1.6	0	0	0
Low	97.8	0	0	0		92.9	0	0	0		95.1	0	0	0
	Low	Medium	High	Extreme		Low	Medium	High	Extreme		Low	Medium	High	Extreme
Emerald														
Extreme	0	0.5	0	0		1.6	0.5	0	0		0	0	0	0
High	1.6	4.9	1.1	0		1.1	0.5	0	0		0	0.5	0	0
Medium	8.2	4.4	0.5	0		2.2	1.6	1.6	0		2.2	1.6	0	0
Low	75.3	3.3	0	0		80.8	9.9	0	0		81.9	11.5	2.2	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	1.1	0.5	0	0		0.5	0.5	0	0		0	0.5	0	0
Low	96.2	2.2	0	0		96.7	2.2	0	0		97.3	2.2	0	0
	Low	Medium	High	Extreme		Low	Medium	High	Extreme		Low	Medium	High	Extreme
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

	One day ahead				Three day ahead				Six day ahead			
Medium	0.5	1.1	0	0	0.5	0	0	0	0	0	0	0
Low	96.7	1.6	0	0	96.7	2.7	0	0	97.3	2.7	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	0.5	0	0	0	1.1	0	0	0
Low	100	0	0	0	99.5	0	0	0	98.9	0	0	0
	Low	Medium	High	Extreme	Low	Medium	High	Extreme	Low	Medium	High	Extreme
Miles												
Extreme	0	0	0	1.1	0	0	0	3.3	0	0	0	1.1
High	0	1.1	2.2	4.4	1.1	2.7	0.5	3.8	0	0.5	0	3.8
Medium	4.9	3.3	1.6	3.3	6.6	2.7	1.6	3.3	3.8	3.3	2.2	9.3
Low	67.6	3.3	1.1	6	65.4	2.2	2.2	4.4	67.6	2.7	2.2	3.3
	Low	Medium	High	Extreme	Low	Medium	High	Extreme	Low	Medium	High	Extreme
Moree												
Extreme	0	0.5	0	0	6.6	1.6	0	0	3.8	0	0	0
High	1.6	1.6	0	0	4.4	0.5	0	0	4.9	0.5	0	0
Medium	9.9	0	0	0	12.1	0	0	0	13.2	1.6	0	0
Low	86.3	0	0	0	74.7	0	0	0	75.8	0	0	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	1.6	0.5	0	0	3.3	0	0	0	0.5	0	0	0
Low	97.8	0	0	0	96.2	0.5	0	0	98.9	0.5	0	0

	One day ahead				Three day ahead				Six day ahead			
	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	1.6	0.5	0	0	2.2	0	0	0	1.6	0	0	0
Medium	11.5	0.5	0	0	11	0.5	0	0	11	1.1	0	0
Low	85.2	0.5	0	0	85.2	1.1	0	0	85.7	0.5	0	0
	Low	Medium	High	Extreme	Low	Medium	High	Extreme	Low	Medium	High	Extreme
Tamworth												
Extreme	0	0	0	0	0.5	0.5	0	0	2.7	0	0	0
High	0.5	1.6	0	0	6	1.6	0	0	1.1	0	0	0
Medium	1.6	0.5	0	0	8.2	0	0	0	7.7	1.1	0	0
Low	95.6	0	0	0	83	0	0	0	86.3	1.1	0	0
	Low	Medium	High	Extreme	Low	Medium	High	Extreme	Low	Medium	High	Extreme
Warwick												
Extreme	0	0	0	0	0	0	0	0	0	0	0	0
High	0.5	0.5	0	3.3	1.1	0	0	3.3	0	0	0	2.7
Medium	3.8	0.5	0	2.2	4.9	0.5	0	3.8	3.8	0	0.5	3.3
Low	83	1.6	1.1	3.3	81.3	2.2	1.1	1.6	83	2.2	0	4.4
	Low	Medium	High	Extreme	Low	Medium	High	Extreme	Low	Medium	High	Extreme
Yanco												
Extreme	0	0	0	0	0	0	0	0	0	0	0	0
High	0	0	0	0	1.1	0	0	0	0.5	1.1	0	0
Medium	2.2	1.1	0	0	2.7	1.6	0	0	3.3	0.5	0	0
Low	95.6	1.1	0	0	94	0.5	0	0	94	0.5	0	0
	Low	Medium	High	Extreme	Low	Medium	High	Extreme	Low	Medium	High	Extreme

Table C3: Contingency tables of forecast vs observed daily maximum AHLU using an upper HLI threshold 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	1.1	0	0	0
Medium	1.1	0	0	0	3.3	0	0	0	3.3	0	0	0
Low	98.9	0	0	0	96.7	0	0	0	95.6	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	4.9	3.3	0	0	2.7	2.7	0	0	1.1	1.1	0	0
Low	91.2	0.5	0	0	93.4	1.1	0	0	94.5	3.3	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	0.5	0	0	0	0	0	0	0
Low	100	0	0	0	99.5	0	0	0	100	0	0	0
	Low	Medium	High	Extreme	Low	Medium	High	Extreme	Low	Medium	High	Extreme
Cessnock												
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	0.5	0.5	0	0	3.3	0.5	0	0	0	0	0	0
Low	98.9	0	0	0	96.2	0	0	0	99.5	0.5	0	0
	Low	Medium	High	Extreme	Low	Medium	High	Extreme	Low	Medium	High	Extreme

One day ahead					Three day ahead				Six day ahead			
Charlton												
Extreme	0	0	0	0	2.2	0	0	0	0	0	0	0
High	0	0	0	0	0.5	0	0	0	1.6	0	0	0
Medium	0.5	0	0	0	1.1	0	0	0	3.3	0	0	0
Low	99.5	0	0	0	96.2	0	0	0	95.1	0	0	0
	Low	Medium	High	Extreme	Low	Medium	High	Extreme	Low	Medium	High	Extreme
Clare												
Extreme	0	0	0	0	0	0	0	0	0	0	0	0
High	0	0	0	0	0	0	0	0	1.6	0	0	0
Medium	0	0	0	0	2.7	0	0	0	1.1	0	0	0
Low	100	0	0	0	97.3	0	0	0	97.3	0	0	0
	Low	Medium	High	Extreme	Low	Medium	High	Extreme	Low	Medium	High	Extreme
Emerald												
Extreme	0	0	0	0	0.5	0	0	0	0	0	0	0
High	0	0	0	0	1.1	0	0	0	0	0	0	0
Medium	7.7	0.5	0	0	1.1	0	0	0	0.5	0	0	0
Low	91.8	0	0	0	96.7	0.5	0	0	98.4	1.1	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
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

One day ahead					Three day ahead				Six day ahead			
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
Miles												
Extreme	0	0	0	0	0	0	0	1.1	0	0	0	0
High	0	0	0	1.1	0	0	0	0.5	0	0	0	0
Medium	2.2	1.1	0.5	3.3	2.7	1.1	0.5	3.8	0.5	0	0.5	4.4
Low	80.8	3.3	1.6	6	80.8	2.7	1.6	4.9	80.8	4.4	1.6	7.7
	Low	Medium	High	Extreme	Low	Medium	High	Extreme	Low	Medium	High	Extreme
Moree												
Extreme	0	0	0	0	0.5	0	0	0	1.1	0	0	0
High	1.1	0	0	0	1.6	0	0	0	2.2	0	0	0
Medium	2.7	0	0	0	9.3	0	0	0	4.4	0	0	0
Low	96.2	0	0	0	88.5	0	0	0	92.3	0	0	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

One day ahead					Three day ahead				Six day ahead			
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	3.3	0	0	0	2.7	0	0	0	1.6	0	0	0
Low	96.7	0	0	0	97.3	0	0	0	98.4	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	1.6	0	0	0
Medium	1.6	0	0	0	8.2	0	0	0	1.6	0	0	0
Low	97.8	0.5	0	0	91.2	0.5	0	0	96.2	0.5	0	0
	Low	Medium	High	Extreme	Low	Medium	High	Extreme	Low	Medium	High	Extreme
Warwick												
Extreme	0	0	0	0	0	0	0	0	0	0	0	0
High	0	0	0	0	0	0.5	0	0	0	0	0	0
Medium	1.1	0	0.5	3.3	1.6	0	0	1.6	0	0	0	2.2
Low	90.7	0.5	0.5	3.3	90.1	0	1.1	4.9	90.7	0	1.1	6
	Low	Medium	High	Extreme	Low	Medium	High	Extreme	Low	Medium	High	Extreme
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	1.1	0	0	0	1.6	0	0	0
Low	100	0	0	0	98.9	0	0	0	98.4	0	0	0
	Low	Medium	High	Extreme	Low	Medium	High	Extreme	Low	Medium	High	Extreme

Table C4: Contingency tables of forecast vs observed daily maximum AHLU using an upper HLI threshold 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	0.5	0	0	0	1.1	0	0	0
Low	100	0	0	0	99.5	0	0	0	98.9	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	0.5	0	0	0	0	0	0	0	0	0	0	0
Low	99.5	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
Cessnock												
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	0.5	0	0	0	0	0	0	0
Low	100	0	0	0	99.5	0	0	0	100	0	0	0
	Low	Medium	High	Extreme	Low	Medium	High	Extreme	Low	Medium	High	Extreme
Charlton												

	One day ahead				Three day ahead				Six day ahead			
Extreme	0	0	0	0	0	0	0	0	0	0	0	0
High	0	0	0	0	2.2	0	0	0	0	0	0	0
Medium	0	0	0	0	0.5	0	0	0	1.6	0	0	0
Low	100	0	0	0	97.3	0	0	0	98.4	0	0	0
	Low	Medium	High	Extreme	Low	Medium	High	Extreme	Low	Medium	High	Extreme
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	2.2	0	0	0
Low	100	0	0	0	100	0	0	0	97.8	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	1.6	0	0	0	1.6	0	0	0	0	0	0	0
Low	98.4	0	0	0	98.4	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
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

One day ahead					Three day ahead				Six day ahead			
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
Miles												
Extreme	0	0	0	0	0	0	0	0	0	0	0	0
High	0	0	0	0	0	0	0	1.1	0	0	0	0
Medium	0	0	0	1.1	0	0	0	0.5	0	0	0	0
Low	89.6	0	3.8	5.5	89.6	0	3.8	4.9	87.4	1.1	3.8	7.7
	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	0.5	0	0	0	3.3	0	0	0	1.6	0	0	0
Low	99.5	0	0	0	96.7	0	0	0	98.4	0	0	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												

One day ahead					Three day ahead				Six day ahead			
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	1.1	0	0	0	0	0	0	0	0	0	0	0
Low	98.9	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	1.1	0	0	0	1.6	0	0	0
Low	100	0	0	0	98.9	0	0	0	98.4	0	0	0
	Low	Medium	High	Extreme	Low	Medium	High	Extreme	Low	Medium	High	Extreme
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	0.5	0	0	0	0	0	0	0
Low	93.4	1.1	0	5.5	92.9	1.1	0	5.5	92.9	0.5	0.5	6
	Low	Medium	High	Extreme	Low	Medium	High	Extreme	Low	Medium	High	Extreme
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

Table C5: Contingency tables of forecast vs observed daily maximum AHLU using an upper HLI threshold 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
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	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
Cessnock												
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
Charlton												

	One day ahead				Three day ahead				Six day ahead			
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	2.2	0	0	0	0	0	0	0
Low	100	0	0	0	97.8	0	0	0	100	0	0	0
	Low	Medium	High	Extreme	Low	Medium	High	Extreme	Low	Medium	High	Extreme
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
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	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
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

One day ahead					Three day ahead				Six day ahead			
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
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	0	0.5	0	0	0	0	0	0	0	0
Low	90.7	2.2	1.6	4.9	90.7	2.2	1.6	5.5	89.6	1.6	2.7	6
	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
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												

One day ahead					Three day ahead				Six day ahead			
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
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	94.5	0.5	0	4.9	94.5	0.5	0	4.9	94	0.5	0.5	4.9
	Low	Medium	High	Extreme	Low	Medium	High	Extreme	Low	Medium	High	Extreme
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

APPENDIX D:

Alternative method for calculating HLI

Introduction

In the preceding text it was reported that errors in the AHLU forecasts arise from two sources – errors introduced by the technique used in calculating the AHLU and errors in the (forecast) HLI. Any disagreement between the observed and forecast HLI can in turn be attributed to errors in the forecasts and errors introduced by the method used to calculate the HLI. Inspection of the graphs of forecast HLI plotted against observed HLI indicates that the performance of the forecasting technique can be considered satisfactory. Comparison of the HLI graphs to the corresponding AHLU graphs reveals that (a) the AHLU graphs show much greater scatter and (b) given that the AHLU is dependent only on the HLI, one might expect the AHLU forecast performance to be similar to the HLI forecast performance.

There is limited scope for improving the quality of the forecasts as these depend on the accuracy of forecasts provided by the Bureau of Meteorology. The other option is to investigate the errors caused by the technique used to calculate the HLI. The aim of this section is to develop alternative method for determining the HLI and AHLU.

Discrepancies caused by the calculation technique

Recall that two expressions are used to determine the HLI – dependent on the BGT being above or below 25 (see Equation 3 in the main report). To illustrate the discrepancy caused by this technique, assume the following (purposely chosen) values for the observed and forecast parameters:

- Forecast and observed relative humidity = 70%,
- Forecast and observed wind speed = 2 m/s,
- Solar radiation = 500 W/m^2,
- Forecast temperature = 18.0 ^{o}C; Observed temperature = 18.2 ^{o}C.

Note that all parameters are equal except for the temperatures which differ by 0.2 ^{o}C. For this set of parameters, one would expect the resulting BGTs and the HLIs to be almost equal. Using Equation 3, we find that the forecast and observed BGTs are 24.9 ^{o}C and 25.1^{o}C respectively – which are almost equal as expected. However, since the forecast BGT value is below the 25^{o}C threshold and the observed BGT value is above the threshold, two different equations are used to determine the HLI. The values thus obtained are 60.6 for the forecast and 74.6 for the observed HLI value – a jump of 14 HLI units. In the example just given, the HLI values are below the lower Thermo-Neutral threshold (77), corresponding to conditions where cattle might be recovering from a previous heat episode. However, the discrepancy in HLI values results in a significant difference in recovery rates between the observed and predicted AHLU values.

To further illustrate this, the forecast HLI values for Amberley plotted against the observed HLI values are shown in Figure D1. Noteworthy features include the majority of data points being grouped into two distinct elongated clusters aligned along the line of unity slope and two sets of lightly populated outliers, labelled “A” in the figure, that represent instances where the two different expressions were used to calculate the HLI. The sharp cut-off at HLI = 50 has not been applied to these data.

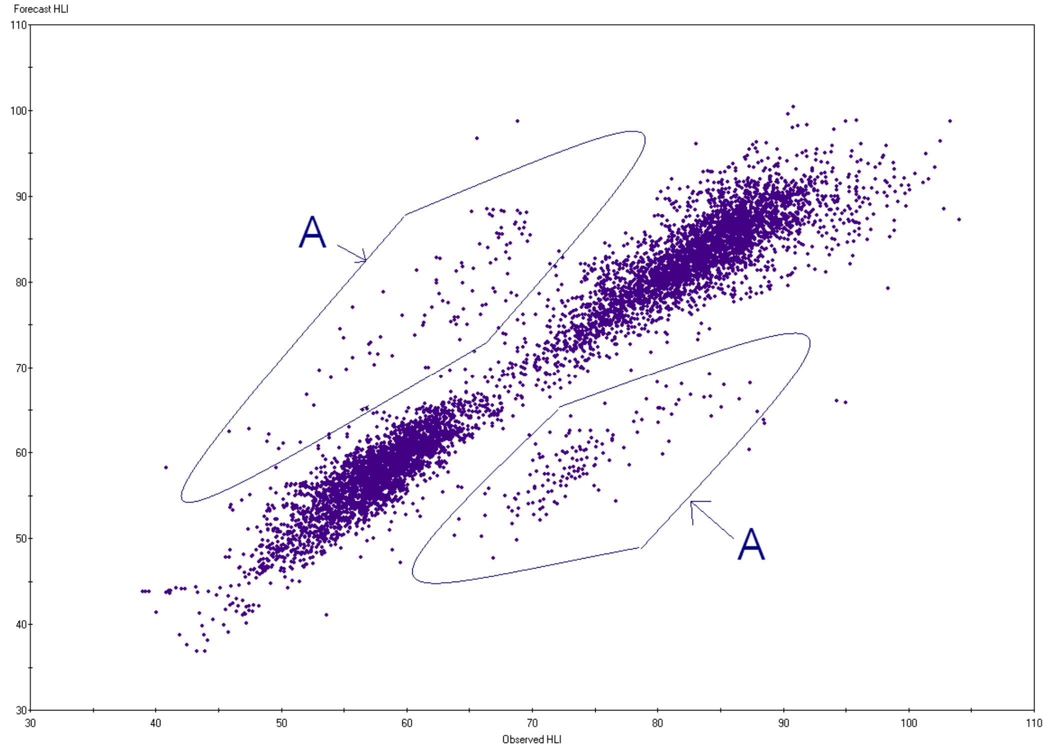

Figure D1: Forecast HLI plotted against Observed HLI. Equation 3 was used to calculate these HLI values.

Brief overview of an alternative method for calculating the HLI

From the preceding discussion, it is evident that an improvement in the forecasts may be possible by making the transition between the two HLI expressions more gradual instead of the sharp step function currently used. To achieve this, a weighting function based on the sigmoid function commonly used for a similar purpose in artificial neural networks has been adapted for this investigation. The form of this function is:

$S(b, m, r) = 1 / (1 + \exp(-X))$

Where

$X = (b – m) / r$

b = BGT value

m = middle of transition region (= 25)

r = rate at which the function switches from one extreme to the other (= 2.25).

The final HLI value is obtained by computing a linear combination of HLI values as follows:

$HLI = F * HLI_{HI} + (1 – F) * HLI_{LO}$

Where

F = S(BGT, 25, 2.25)

HLI_{HI} = HLI value determined using the expression for BGT >= 25

HLI_{LO} = HLI value determined using the expression for BGT < 25

A plot of this function is shown in Figure D2. The value of this function is 0.5, or 50%, for a BGT of 25, resulting in equal contributions from each HLI expression at the BGT value where calculation of HLI switches between the two expressions. This midpoint value is set by the "m" parameter. The value of the rate parameter "r" (= 2.25) was chosen so that for a BGT value of 20, the HLI value consisted of 10% HLI_{LO} and 90% HLI_{HI}, with the reverse combination for a BGT value of 30. Note that for this example, the value of "r" (2.25) and the 10% and 90% function values were arbitrarily chosen. The effects of varying "r" will be discussed in the next section. The intention of this section is only to introduce the method and illustrate what can be achieved.

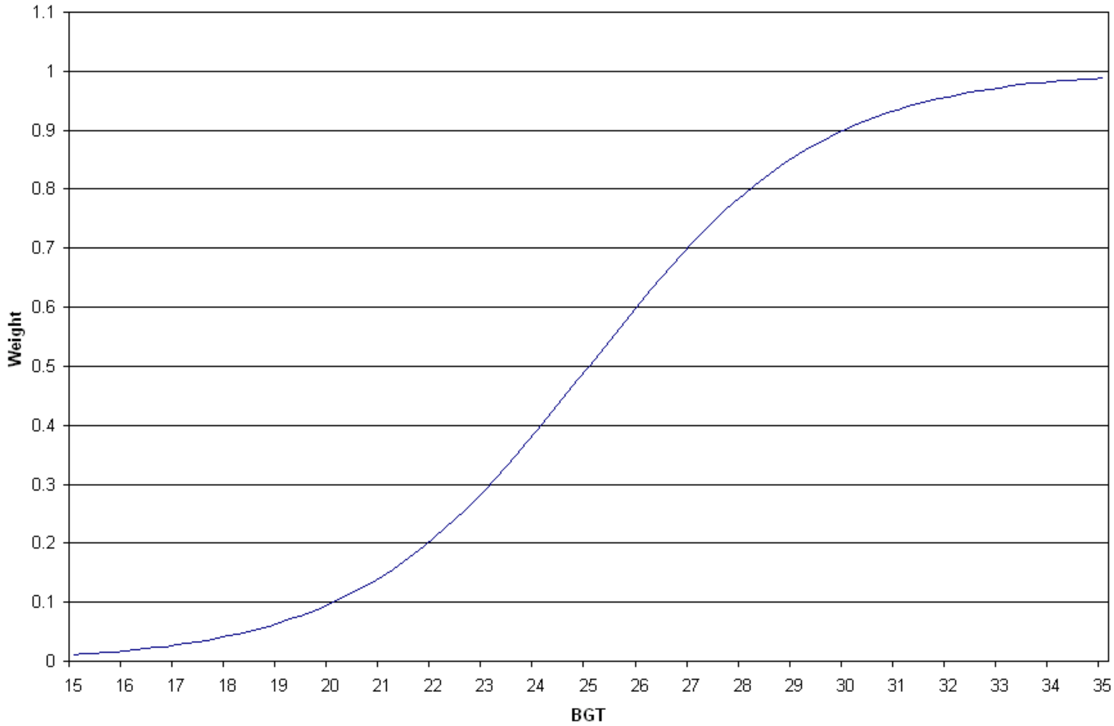

Figure D2: Plot of modified sigmoid function.

Figure D3 shows the forecast HLI values for Amberley plotted against the observed HLI values using the alternative technique described above. Comparing Figure D3 to Figure D1, we see that the outliers have been removed and the gap between the two major clusters is less distinct. This plot is what would be expected for this type of graph. The scatter represents the error inherent in the forecast parameters that were used to calculate the plotted quantities. It should be emphasised that the HLI parameters shown in Figures D1 and D3 are strictly not the same. These have been calculated using different methods and, whilst they are similar, these should not be thought as being the same.

An important issue that must be addressed is how faithfully the HLI values obtained with the new method mimic the HLI values obtained with the current method. There would be little point in developing an alternative method if it did not represent the HLI values as adequately as the existing method. This issue cannot be resolved by relying on the scatter plots alone. Further insight can be gleaned from the temporal behaviour of the relevant variables. This is shown in Figure D4.

In this figure, the solid traces represent the HLI time series obtained using the new method with observed and forecast values of relative humidity, temperature and wind speed. The dotted traces represent the HLI time series using the current method with observed and forecast values of relative humidity, temperature and wind speed.

It is evident from Figure D4 that the HLI obtained with the new method compares favourably to the current method. The gross behaviour is reproduced very well – the agreement between the two methods is very good. Discrepancies between the new and current methods exist in the finer detail, however these are of the same magnitude as the discrepancies between forecast and observed values. Overall, it appears that the current method can be upgraded without losing the physical significance of the HLI.

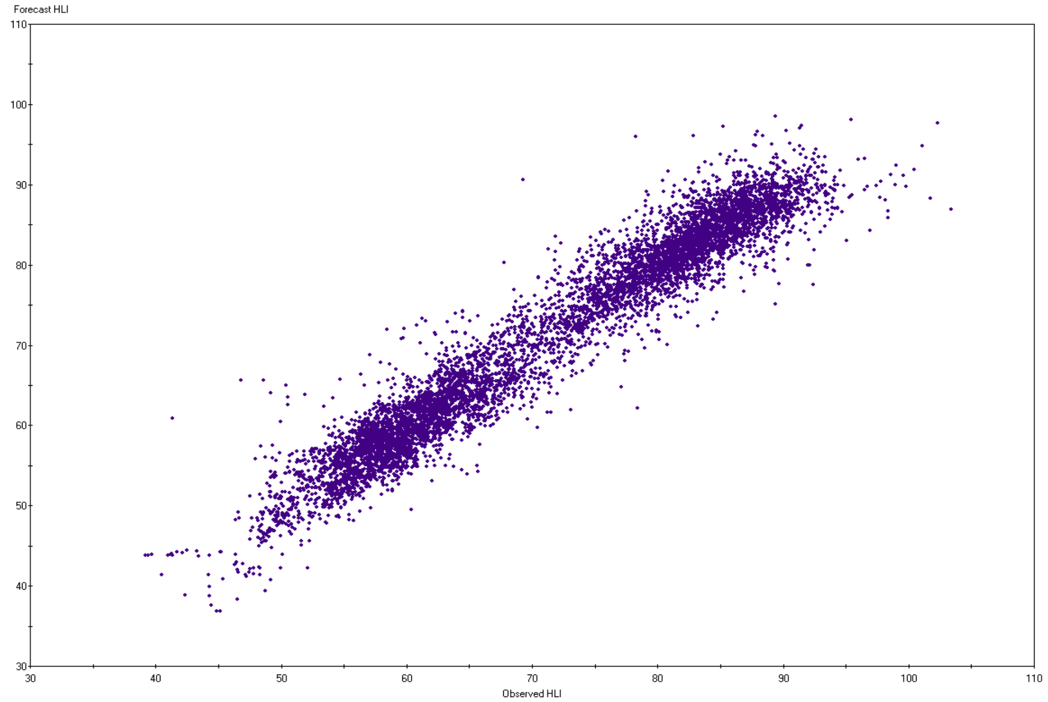

Figure D3: Forecast HLI plotted against Observed HLI. HLI values were calculated using the alternative method

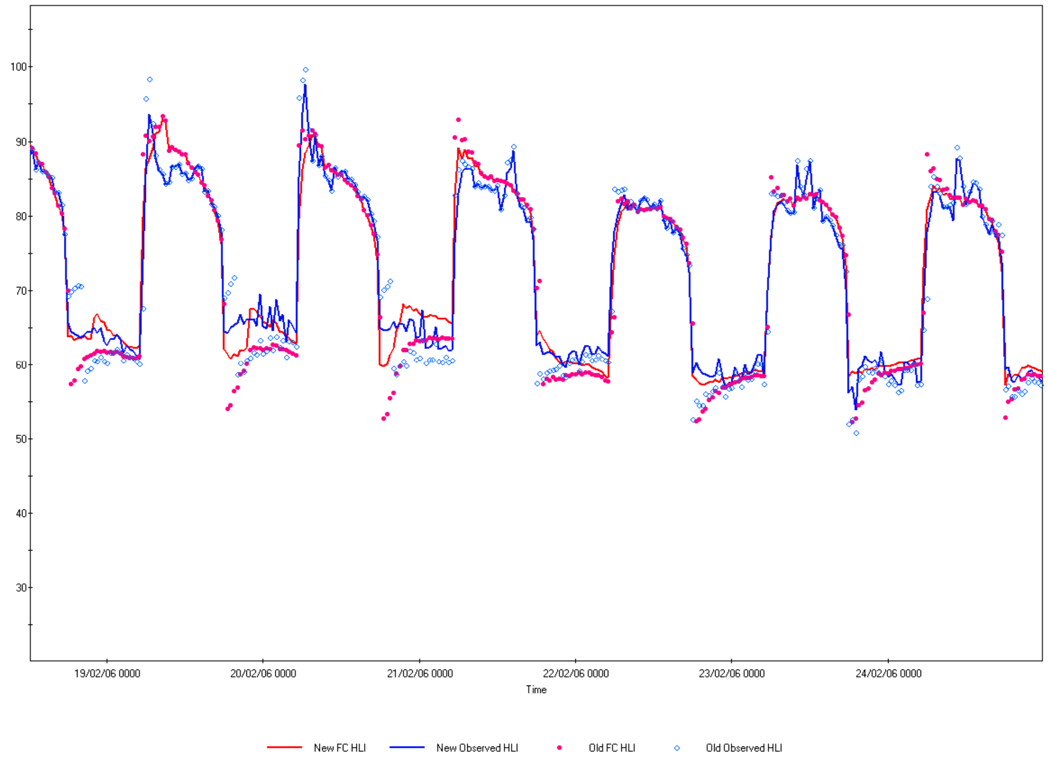

Figure D4: Time series of HLI values calculated using current and alternative methods.

Effects of varying the rate parameter "r"

The form of the weighting function is determined by two parameters, "m" and "r". The "m" parameter shifts the function along the BGT axis thus specifying the BGT value where the contributions from the two expressions for calculating the HLI are equal. The "r" parameter governs the rate that the function switches from one extreme to the other. The size of the BGT interval that the function varies from 0.1 (10%) to 0.9 (90%) is linearly related to "r". This interval we shall define as the "transition width" or TW. Note that this definition does not result in loss of generality – i.e. choosing values other than 0.1 and 0.9 only changes the proportionality constant relating "r" and the transition width.

To ascertain the effects or varying "r", HLI values using observed and forecast meteorological parameters were determined and the resulting forecast HLI were plotted against observed HLI for various values of "r". The results are shown in Table D1. The measure used to quantify the effects of various "r" was the Pearson Correlation Coefficient. Also included in the table are the parameters specifying the line of best fit and the transition width associated with each "r" value.

Table D1: Effects of varying "r" on the relationship between forecast and observed HLI values for Amberley.

"r"	Transition width, TW	Pearson	Slope	Intercept
0.0	0	0.957	0.961	2.48
0.5	2.2	0.968	0.973	1.62
1.0	4.4	0.970	0.978	1.29

"r"	**Transition width, TW**	**Pearson**	**Slope**	**Intercept**
1.5	6.6	0.971	0.979	1.19
2.0	8.8	0.970	0.979	1.21
2.5	11.0	0.969	0.978	1.29
3.0	13.2	0.969	1.01	1.56

From the above table, the following can be deduced:

- The transition width is linearly related to "r". The relationship is TW = 4.4 * r.
- The original data are well correlated with the outliers forming a small part of the overall population. Consequently, the correlation coefficient is high and any improvements would manifest as small increases in the correlation coefficient.
- The largest increment in the correlation coefficient occurs between "r" = 0 to "r" = 0.5. Thereafter, any increase is relatively small, indicating that even a small amount of "blending" of the two HLI functions produces a noticeable improvement.
- For this data set, the best improvement occurs with an "r" value of 1.5 – i.e. TW of 6.6.
- The weighting function is mathematically undefined for "r" = 0. This case corresponds to an infinitely fast transition between the two expressions used to determine the HLI – it is in fact a mathematical representation of the method currently used.

The above procedure was repeated using data from Charlton, Victoria. The results are shown in Table D2.

Table D2: Effects of varying "r" on the relationship between forecast and observed HLI values for Charlton.

"r"	Transition width, TW	Pearson	Slope	Intercept
0.0	0	0.963	0.990	2.67
0.5	2.2	0.968	1.00	2.21
1.0	4.4	0.971	1.00	1.92
1.5	6.6	0.972	1.01	1.76
2.0	8.8	0.973	1.01	1.63
2.5	11.0	0.973	1.01	1.53
3.0	13.2	0.973	1.01	1.45

Comparing Table D1 to Table D2 shows that the trends are similar in both cases. For Charlton, the effect levels out at a TW of about 8.8. Figure D5 shows the forecast HLI obtained with the current method plotted against the observed HLI. Note again the similarities with the Amberley data. Figure D6 shows the HLIs obtained with the method described here using a TW of 8.8.

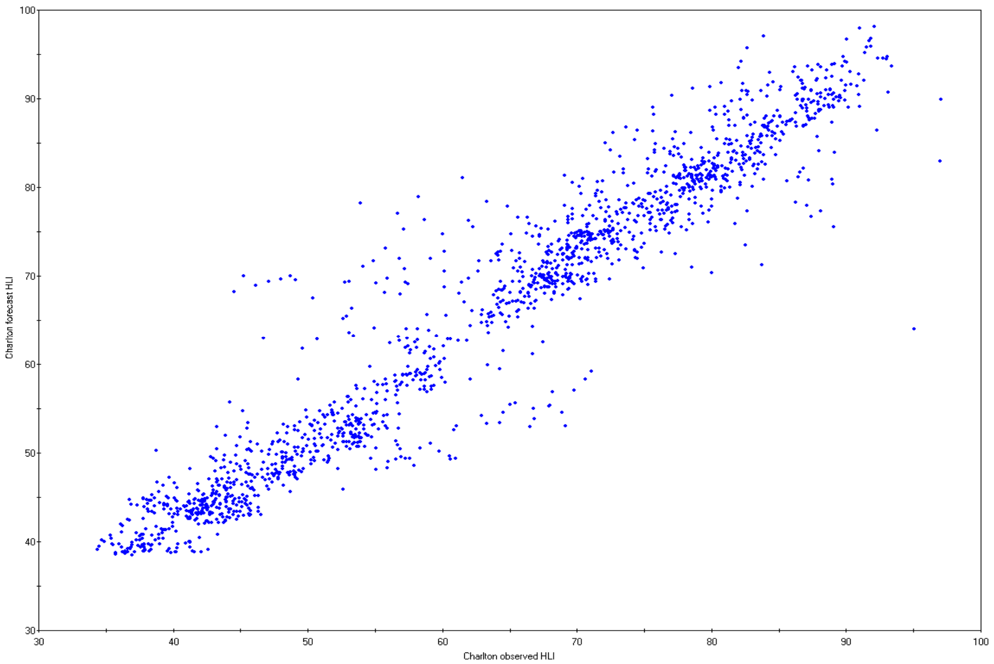

Figure D5: Forecast HLIs plotted against observed HLIs for Charlton using the current method.

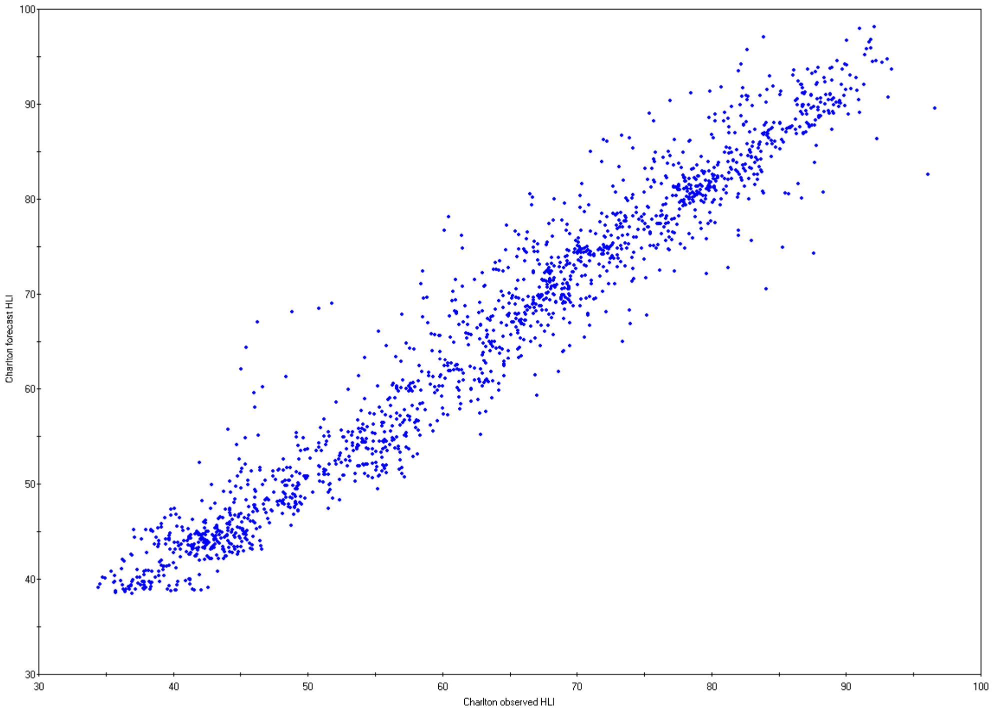

Figure D6: Forecast HLIs plotted against observed HLIs for Charlton using the alternative method.

Again the outliers, which initially are small in number, have been removed and the gap between the two major clusters, which is clearly visible in Figure D5 cannot be discerned in Figure D6.

AHLU calculations

It has been stated that there are two causes of discrepancies or error between the observed and forecast AHLU. These are the uncertainty inherent in the HLI forecasts and errors introduced by the manner in which the AHLU is calculated. New AHLU values (both forecast and observed) were calculated using the HLI obtained with the method described above. The results – forecast plotted against observed AHLU – showed no noticeable improvement, indicating this error in the HLI is not a major cause of error in the AHLU. Since the number of outliers (the outliers in Figure D1) is small in comparison with the overall data set, we would indeed expect a correspondingly small change in the resultant AHLU. The remaining cause of error - the method used to calculate the AHLU – appears to be the main cause and this will now be discussed.

The calculation of AHLU values shares similarities with HLI calculations in that there are thresholds or sharp cutoffs and different procedures are employed depending on whether the HLI is above or below these thresholds. Complications arise because there are two thresholds: the upper and lower boundaries of the Thermo-Neutral zone. The lower boundary is set at a HLI value of 77. For HLI values below this threshold, the AHLU decreases at a rate of half the difference between the HLI and the threshold. For HLI values above the upper Thermo-Neutral zone threshold, the AHLU increases at a rate equal to the difference between the HLI and the threshold. For HLI values within the Thermo-Neutral zone, the AHLU remains unchanged. Furthermore, the upper Thermo-Neutral zone threshold is variable, depending on the condition of the stock in the feedlot.

Several (but by no means exhaustive) attempts were made at replacing the step functions with continuous functions in a manner similar to that implemented for the HLI calculation, however the results were not satisfactory. Issues which became apparent are:

- The current method calculates an AHLU increment obtained by taking the difference between the HLI value and a threshold. If weighting functions were to be used, an alternative scheme for finding an equivalent to this difference would have to be devised.

- Replacing the two thresholds with two weighting functions is not straight forward as the weighting functions tended to overlap in the Thermo-Neutral zone giving two values for the AHLU increment. It was not clear how a final AHLU increment should be assigned.

- Different weighting functions are required for different upper Thermo-Neutral zone thresholds, although this is a “technical difficulty” can be overcome once the other issues are resolved.

The above indicate that a different approach is required to arrive at a method for determining AHLU values that are consistent with the method that is currently used – mainly how the situation for HLI values within the Thermo-Neutral zone should be treated. However, the results obtained for the HLI indicate that avenues based on the approach described above show promise for AHLU calculations and should be investigated further.

Summary

An alternative method for calculating the HLI is presented. Investigations into finding an alternative method were carried out because the current method, which utilises two different expressions, can result in large discrepancies in HLI as the transition is made between the two expressions. The HLI values calculated using this alternative method consist of a blend of values from each expression.

Better agreement was found between the HLI values obtained using this method, in that the scatter plot did not show the outliers that result from the sudden switching between the two expressions and that the temporal behaviour of the new HLI values were consistent with values determined using the current method. However, the improved performance of forecasting the HLI did not result in an improvement in the ALHU.

A similar approach was used to implement a method for determining the AHLU, however, this gave unsatisfactory results. It was found that the two thresholds (the upper and lower limits of the Thermo-Neutral zone) and the requirement that that the effect on the AHLU be zero for HLI values within the Thermo-Neutral zone ultimately gave rise to poor correlation between the observed and forecast AHLU.