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Prepared by: Michael McCarthy
Global Livestock Solutions Pty Ltd
and
Li Fitzmaurice
Pacific Environmental Limited

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Meat and Livestock Australia Limited
Locked Bag 1961
NORTH SYDNEY NSW 2059

Heat load forecasting review

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Abstract

Heat load forecasting within the Australian feedlot industry has evolved over a 15 - 20 year period to become a world class, multi-faceted forecasting service. The model at the centre of the service is elegantly simple in its approach and provides an outstanding framework from which to address heat stress (and more importantly) heat load. The model factors the weather (both predicted and actual), the types of cattle, the feedlot in question and the importance of the management practices involved.

There is a contradiction, however, as on the one hand the industry possesses a world class, sophisticated model, but on the other, the model struggles at times, to accurately predict a heat load event. This review identifies the limitations and shortcomings of the service and explains the inconsistencies that are sometimes evident. It makes recommendations as to how the service might be improved and/or better utilised.

Executive Summary

Heat load forecasting within the Australian feedlot industry has evolved over a 15 - 20 year period to become a world class, multi-faceted forecasting service. Initially, the service consisted of a number of basic tools aimed at helping feedlot managers address and manage the risk of heat stress. However, the feedlot industry quickly embraced the concept of accumulative heat load (which factors both the intensity and duration of exposure to heat) and further, recognised the importance of solar radiation as a heat source and wind speed to assist in heat loss. The importance of weather forecasting to prepare for, and manage heat load was also recognised. As a result, the initial tools have been refined and combined into a sophisticated forecasting model that factors the weather (both predicted and actual), the types of cattle, the feedlot in question and the importance of the management practices involved. The heat load forecasting service is delivered by Katestone Environmental Pty Ltd, a Brisbane based environmental consulting firm.

The service has become even more sophisticated with the introduction of on-site weather stations to measure the weather at the feedlot and reset the calculated heat load in the animals based on actual weather information. Individual feedlots are now far more involved. Paradoxically, this has highlighted inconsistencies in the forecasting and has led, in some cases, to a loss of confidence in the service. As a result, the industry has started to question some of the basic tools that have served the industry so well in the past.

In view of the above, this review has been commissioned to identify any current deficiencies in either the heat load modelling and/or the weather forecasting. It is hoped that this will better define the limitations and shortcomings of the service and better align expectations to what is actually delivered. It is hoped, also, that this will restore confidence in many of the tools that are inherent in the model and encourage them to be used appropriately within what is a world class, highly sophisticated approach to heat stress management.

Apart from an overview of the key industry project reports, the review has relied heavily on industry consultation to determine the workings of the service and identify the issues involved. It has been undertaken by systematically breaking down each aspect of the model into its smallest possible components. This has highlighted the multifaceted nature of the service and the very large number of factors involved. The reviewers also noted how errors can be quickly amplified within what is necessarily a highly sensitive model.

Furthermore, the review found that, of the inconsistencies that were investigated, very few of them were caused by deficiencies in the model and/or forecasting service. For the most part they were attributable to equipment failure, glitches to do with data transfer and/or misinterpretation of information. If this is representative of all the inconsistencies, then the service is being held in question unfairly. The only way for this to be resolved is for all inconsistencies to be quickly and effectively investigated.

The review came to a number of important conclusions. This first is that there is no ‘silver bullet’. There are no glaring deficiencies that, once rectified, will allow the service to accurately predict heat load under all circumstances. The reviewers did, however, note shortcomings and limitations in nearly all the facets of the model, all of which have the capacity to compromise the accuracy of the forecast.

Based on the industry consultation, it would seem that the extent of these shortcomings and limitations has not been well communicated to the industry. This has led to false expectations that are partly responsible for the change in emphasis away from the service as a management tool and toward a service that is expected to precisely predict a heat load event.

The second conclusion is therefore that the forecasting service should re-position itself and promote the service as a management tool and better qualify the expectations in regards to the precise prediction of a heat load event. In the interim, the industry should make every effort to improve the accuracy of the forecasting service by addressing all the facets of the model.

The reviewers major finding is that there is a lack of understanding about the assumptions (and/or the implications of the assumptions) within the model. These are highlighted throughout the report. There are many knowledge gaps. These relate to the heat load index (HLI) algorithm, the method by which heat load is calculated, the HLI threshold adjustment factors and finally, the site specific weather forecasting. These are discussed in more detail under the heading ‘Explaining inconsistencies within the model’. These discussions highlight the biological complexity behind the assumptions within the model. They also demonstrate that a model that accurately reflects all the biology would be exceedingly complicated.

The third conclusion is that, although the existing model is simplistic, it should be retained; but efforts should be made to better understand the implications behind the assumptions involved. This aim is to furnish the industry with a simple model that is supported by a strong understanding of its limitations and shortcomings. This would assist in quickly identifying the circumstances in which the model could be found to be inaccurate.

It should be noted that although the model’s threshold adjustment factors were determined scientifically through regression analysis (Gaughan *et al.* 2008), the basic assumptions of the HLI algorithm have yet to be properly validated. At the upper end of HLI, the index can be calibrated to some extent, by observing an animal’s response. However, what happens at the lower end is far more speculative, since heat load (and the shedding of heat load) is very difficult to measure. Furthermore, the regression analysis may provide a scientific basis for determining adjustment values, but this still falls a long way short of the validation that is required for a full understanding of how the biology links to the workings of the model.

This is demonstrated more clearly in the tables provided in Chapter 6.1.1 (‘Explaining inconsistencies within the model’) whereby each adjustment factor is assessed on the basis of the criteria used, the strength of the linkages involved, the scientific validation and the presence of any ‘exceptions to the rule’. These tables highlight the ‘loose’ nature of many of the linkages involved.

It was concluded that the site specific weather forecasting is a sensible compromise between accuracy and practicality and/or cost. There are issues relating to localised weather events and the use of automated weather stations (AWS).

The review recommendations stem directly from the conclusions. Apart from a relatively short list of initiatives that could be implemented immediately, the review recommends that the industry makes every effort to deepen its understanding of the assumptions within the model. The review recommends that this should be achieved by more detailed study around the way in which animals accumulate and shed heat load (this would most likely require controlled heat rooms) and accompanied further by theoretical work that explores the concepts of energy balance and alternative methods of simulating heat load.

The review notes the glaring need for industry feedback and validation. It recommends that the industry work more closely with researchers to provide feedback and validation as part of a formal, structured validation project. It suggests that more work be undertaken to ensure that feedlot managers are more informed about the threshold adjustment factors to allow them to better and more accurately attribute adjustments based on the factors involved. It is also suggested that acclimatisation may be responsible for many of the inconsistencies seen within the model and should therefore be singled out for more attention. Despite the good work that has already been undertaken, a study that takes a more commercial approach to summer feeding strategies would pull together much of the work that has been already undertaken. This study would consider both dry matter intake and cost of gain, whilst at the same time examining how a ration affects heat production.

The industry acknowledges the issues surrounding the use of AWSs. These issues relate to the siting, installation, calibration and maintenance of the AWS equipment, and maintaining their connectivity to the forecasting service through the Heat Load Data Network (HLDN). There are many possible points of failure, both in the measurement of the weather elements, and in the transfer of information. Without a vigorous quality assurance program in place, the integration of data into the heat load forecast would seem problematic. The danger is that these errors remain undetected and become imbedded into the forecasting service. The propensity of the heat load model to amplify small errors is explained.

The industry is somewhat divided on what to do with the on-site AWS. There is a school of thought that suggests that the AWS should be removed and another that suggests it should be retained. At this point, it is recommended that integration of data from the onsite AWS be retained, but it is strongly recommended that it be subjected to a vigorous quality assurance program. A co-ordinated approach is required that involves, not only Katestone staff but also feedlot staff, equipment sellers and/or any other information hubs that are involved in the HLDN. The situation should be reviewed in 2-3 years and if the issues have not been resolved, a different adjudication may be required.

There are other recommendations (relating to the use of terminology, consistency of message, some minor model adjustments, and the preparation of extension material). These are outlined under appropriate headings.

The Katestone Cattle Heat Load Toolbox (CHLT) is delivered via a web based site that provides a suite of tools that assist feedlot managers to prepare for, and manage a heat load event. The general consensus is that the Katestone website is too ‘busy’ and should be ‘stripped back’ and simplified. The reviewers agree with this sentiment; however, it is recommended that changes to the website be postponed until after (or at the same time) as the preparation of the suggested extension material. It may also be prudent to make these changes opportunistically (e.g. for example, at the same time as there is a change to the website software platform). Consideration of a simpler design could begin immediately.

Finally, based on a thread of logic associated with the rate of heat dissipation from an animal under heat load (see Figure 1, Chapter 6.1.1) the reviewers have boldly quantified the energy value of one accumulated heat load unit (AHLU). One AHLU is quantified as 46W or 0.17MJ/hr. On this basis, an accumulated heat load of 50 units would be equivalent to 8.5 MJ. This determination should be subjected to more scrutiny, but if it holds, it provides a pivotal link to a more sophisticated energy balance approach that could determine the required rate of heat loss in each of the heat loss compartments (Thompson *et al.* 2014).

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1 Introduction

Heat load forecasting within the Australian feedlot industry has evolved over a 20 year period to become a sophisticated, multi-faceted forecasting service. Initially, the service consisted of a number of basic tools aimed at assisting feedlot managers to address and manage the risk of heat stress. However, the feedlot industry quickly embraced the concept of heat load (which factors both the intensity and duration of exposure to heat) and further, recognised the importance of solar radiation as a heat source and the importance of wind speed to assist in heat loss. The importance of forecasting to prepare for, and manage heat load was also recognised. As a result, the initial tools have been refined and combined into a sophisticated forecasting model that factors the weather (both predicted and actual), the types of cattle, the feedlot in question and the importance of the management practices involved.

More recently, as feedlots have become more involved, the emphasis has changed from a service that provides the tools to assist feedlot managers address and manage the risk of heat load, to a service that is expected to precisely predict heat load events. Paradoxically, this sophistication has also made it easier to identify inconsistencies in the forecasting and this has resulted, in some isolated cases, in a loss of confidence in the service. Sadly, this loss of confidence has led the industry to question some of the basic tools that have served the industry so well in the past.

In view of the above, this review has been commissioned to identify any current deficiencies in either the heat load modelling and/or the weather forecasting. It is hoped that this will better define the limitations and shortcomings of the service and better align expectations to what is actually delivered. It is hoped, also, that this will restore confidence in many of the powerful tools that are inherent in the model and encourage them to be used appropriately within what is a world class, highly sophisticated approach to heat stress management.

2 Background

2.1 Early work

Although heat stress had been studied previously in Australia, the earliest documented work was summarized in a paper by Young in 1993 (Young 1993). This pointed out the importance of heat stress in terms of the economic cost and the cost to animal welfare. It also pointed out that there were gaps in the understanding of the mechanisms of heat stress and the way in which the effects of heat stress might be mitigated. Incidents in the late 1990's prompted the feedlot industry to address heat stress more formally (Entwistle 2000).

Around this time, pivotal work was being conducted in the United States. Australian researchers were monitoring this work and in some cases involved (Mader *et al.* 1998). In 2000, Meat & Livestock Australia (MLA) launched a concerted effort to address heat stress in the Australian feedlot industry. A comprehensive literature review was completed that detailed everything that was known about heat stress at the time (Sparke *et al.* 2001). This was a pivotal study that has underpinned nearly everything that has evolved since.

2.2 Industry work

The literature review was followed by a review of the way in which both cattle and the microclimate were assessed during periods of high heat load (Gaughan *et al.* 2002). This, and the development of a trial weather forecasting service (Katestone Scientific Pty Ltd 2002; Katestone Environmental Pty Ltd 2003), supported by onsite monitoring (EA Systems Pty Ltd 2001, 2003) allowed the industry to develop a heat stress risk assessment program (RAP) (Gaughan *et al.* 2003a). The initial model was designed to determine intensity related short-term heat stress thresholds only, using the temperature and humidity index (THI), but further work allowed the model to consider accumulated heat load through the use of THI hours (Gaughan and Castenda 2003).

Around that time, work in Australia and in the United States had shown that heat stress was not simply a function of temperature and humidity, but also a function of solar radiation and wind speed. As a result, a heat load index that factored both solar radiation and wind speed was introduced (Gaughan *et al.* 2003a). The new index was followed by validation work (Byrne *et al.* 2005b) and a revision of the risk analysis program (Jackson and Killip 2006).

Around this time, It was noted that the risk of heat stress was influenced by the extent to which night time cooling was able to reduce the heat load (Mader *et al.* 2006). As a result, a further new heat load index was developed to better accommodate the way in which the accumulated heat load was calculated (Byrne *et al.* 2006). A key component of this model were assumptions about the way in which heat is accumulated as well as the way in which it is shed. This is influenced by the threshold factors that were determined by the risk assessment program (RAP). The methodology used to determine the index and its threshold factors is described in the scientific paper 'A new heat load index (HLI) for feedlot cattle' published in the Journal of Animal Science (Gaughan *et al.* 2008).

The ability to link the model to a weather forecasting service, provided the industry with the ability to predict and manage a heat stress event (Katestone Pty Ltd 2004). The current forecasting model is therefore the product of a series of reviews and updates over a 15 - 20 year period. It should be noted, however, that although the threshold factors were determined by the regression analysis of a large data set, the large number of factors involved diminishes the numbers in each subset. Consequently, it has been stated from the outset that further validation is required for both the model and its threshold factors (Gaughan pers. comm.).

To date, efforts to validate the model have assumed the integrity of the threshold factors. Conversely, efforts to validate the threshold factors have assumed the integrity of the model. Neither have been evaluated in isolation. Although efforts to validate the model have been ongoing, it is clear that the task is challenging and a comprehensive, practical method of validation with sufficient power to deliver high levels of confidence has remained elusive.

With the assistance of the services provided by Katestone Environmental Pty Ltd, the model has been crafted into a dynamic, world class heat load forecasting service with a sophisticated web based industry interface (Katestone Environmental Pty Ltd 2013a). The service has grown from 16 forecast locations (in 2005) to 319 forecast locations (in 2015) (Katestone Environmental Pty Ltd 2016b). There are currently 440 subscribers and 228 user sites (221 feedlots and 7 abattoirs). The service covers nearly a million head of cattle across Australia.

In addition to the previously mentioned studies, the industry has commissioned several studies that address a range of management initiatives that can be used to reduce the risk of heat load. These include the use of shade (Binns *et al.* 2003; Gaughan 2008a, 2008b), the cooling of water (EA Systems Pty Ltd 2004) and the use of dietary manipulation (Kennedy and Cronje 2005; Gaughan and Mader 2007; Kennedy 2008). The industry has proactively disseminated these measures through the use of well prepared and informative extension material, such as ‘Tips and Tools - Heat Load in Feedlot Cattle’ and a number of factsheets (AUSMEAT 2006; Meat & Livestock Australia 2006; Department of Agriculture Fisheries and Forestry (DAFF) QLD 2012).

The service is supported by the National Feedlot Accreditation Scheme (NFAS) whereby the ability to calculate heat load and conduct a heat load risk assessment is a condition of accreditation (see Appendix).

The requirement for heat stress incidents to be reported has also been communicated to the industry in keeping with the NFAS (AUSMEAT 2013, 2015). More recently, the industry has run a series of workshops that better explain how to get the most out of the service and how to manage heat stress should it occur (Katestone Environmental Pty Ltd 2015c). This project therefore builds upon a very large body of work.

3 Project objectives

The objectives of the heat load forecasting review are to:

1. Identify any current deficiencies in the heat load index model used to predict the animal response to periods of Excessive Heat Load across a range of locations, feedlot sites, cattle types and market categories.
2. Identify any current deficiencies in the accuracy of site specific weather forecasting.
3. Make recommendations as to any improvements that could be made to the current heat load and weather forecasting models.

4 Methodology

The review was primarily undertaken by industry consultation, but it was preceded by the reviewers becoming familiar with any relevant industry material.

4.1 Review of relevant industry material

A reading list was determined by MLA program managers and the consultants familiarised themselves with this work prior to undertaking the project. Many of these have been referred to in the introduction.

4.1.1 Key industry project reports

This initial list included the following project reports:

FLOT.307, FLOT.308 and FLOT.309 – Heat load in feedlot cattle (Sparke *et al.* 2001)

FLOT.313 – Development and trial of a weather forecasting service for excessive heat load events for the Australian Feedlot Industry (Katestone Scientific Pty Ltd 2002)

FLOT.316 – Excessive heat load index for feedlot cattle (Gaughan *et al.* 2003a)

FLOT.319 – Refinement of the heat load index based on animal factors (Gaughan and Castenda 2003)

FLOT.324 – Refined website based forecast for the Australian feedlot industry (Katestone Pty Ltd 2004)

FLOT.327 – Reducing the risk of heat load in the feedlot industry (Byrne *et al.* 2005a)

FLOT.330 – Validation of the heat load for use in the feedlot industry (Byrne *et al.* 2005b)

FLOT.335 – Improved measurement of heat load in the feedlot industry (Byrne *et al.* 2006)

FLOT.336 – Revision of the Risk Analysis Program (RAP) (Jackson and Killip 2006)

BFLT.0343 – Amelioration of heat stress in feedlot cattle by dietary means (Kennedy 2008)

B.FLT.0357 – Upgrade to the feedlot cattle heat load forecast service (Katestone Environmental Pty Ltd 2010a)

B.FLT.0380 – Feedlot AWS data integration (Katestone Environmental Pty Ltd 2015b)

BFLT.0381 – Updated heat load index algorithm (Katestone Environmental Pty Ltd 2015d)

B.FLT.0386B – Cattle heat toolbox upgrade (Katestone Environmental Pty Ltd 2013a)

B.FLT.0386A – Weather station review (Katestone Environmental Pty Ltd 2013c)

4.1.2 Web-based information

Katestone Environment Pty Ltd (2015) Cattle Heat Load Toolbox. http://chlt.katestone.com.au/

4.1.3 Key industry extension material

This initial list included the following extension material:

AUSMEAT - Excessive Heat Load Guidelines

AUSMEAT - Excessive Heat Load Monitoring and Incident Reporting

DAFF Qld - Animal Welfare in Beef Feedlots - Heat Stress Management

MEA - Feedlot Weather Station

MLA - Tips and Tools - Heat Load in Feedlot Cattle

4.1.4 Additional material

Additional material that contained useful information was identified during the course of the project. This is referenced throughout the document, and included the forecasting reviews that have been conducted by Katestone on an annual basis since 2004 (Katestone Environmental Pty Ltd 2005, 2007, 2009, 2010a, 2010b, 2011a, 2011b, 2013b, 2014, 2015a, 2016b). The implications of climate change and the increased risk of extreme weather events was also noted (Yapp *et al.* 2011).

4.2 Industry consultation

4.2.1 Meeting with MLA program managers

The inception meeting was held on 9th May 2016. This meeting provided a background to the industry heat load forecasting and outlined the approach and required terms of reference of the project. A date for the industry meeting was set as the 3rd June 2016. Preliminary meetings were organised with two key industry personnel.

4.2.2 Meetings with key industry personnel

The preliminary meeting with John Gaughan took place on the 1st June 2016. This meeting focussed mostly on the development of the model and the science that underpins its assumptions. Notes of the meeting have been included in earlier milestone reports.

The preliminary meeting with Katestone took place on 2nd June 2016. This meeting focussed mainly on weather forecasting and the delivery of the service. Notes of this meeting are also included in earlier milestone reports.

4.2.3 Industry meeting

The industry meeting was held on 3rd June 2016. This included attendance by a substantial number of key industry figures, ranging from feedlot managers to industry consultants. The attendance list and meetings notes are included in the earlier milestone report.

4.2.4 Meetings with individuals/small groups/working parties

Regular meetings with key industry personnel were held throughout the course of the project. This included one off meetings with a number of key stakeholders and visits to several feedlots. These meetings are documented in the Appendix.

4.3 Review of heat load forecasting

The review has been undertaken by systematically breaking down each aspect of the model into its smallest possible component. It introduces each heading with a precis of what the heading is about and then follows it with any issues or relevant points that have been identified through the course of consultation.

The report makes a distinction between what is considered a tool and what might be considered a service. This has particular relevance when considering a tailored service, aimed to suit a particular situation or business house. The Cattle Heat Load Toolbox (CHLT) in its current form could be described as including the following tools: the weather forecasting model, the HLI index, the HLI model, the HLI threshold calculator, the AWSs (although owned by the feedlot) and the HLDN.

The forecasting service utilises these tools in the delivery of the service. This includes the delivery of the weather forecast (temperature, relative humidity, solar radiation, and wind speed) for a particular location, the calculation of HLI, the upload of AWS weather information through the HLDN, the calculation of the upper HLI threshold limit and the calculation of heat load based on AHLU. These are discussed in more detail throughout the report.

5 Results

This chapter outlines the results of the review. The review relied heavily on industry consultation to identify any current deficiencies. The review therefore reflects the views and concerns of individuals from within the industry[1]. Wherever possible, statements have been subjected to a 'fact check' by referring to the industry material and/or conferring with those who may have been present when events were unfolding. Inevitably, there may be some statements that are either incorrect or have been misconstrued due to industry misunderstanding. For the most part, however, it is clear that the industry sees the forecasting service as a work in progress and is aware that it has both strengths and its deficiencies. This section endeavours to present the findings of the review within an organised and logical framework.

5.1 Review of the heat load modelling

The heat load model has three working components. The first is the heat load index (HLI) itself, the second is the way in which heat load is calculated to determine the accumulated heat load units (AHLU) and the third is the setting of alert levels based on the accumulated heat load. The HLI has been referred to as the 'front end' of the model. It is generally felt that the HLI does an acceptable job of quantifying the environmental challenge. This applies to both forecast and actual weather (as measured by on-site AWS).

The way in which accumulated heat load is calculated has been referred to as the 'back end' of the model. This part of the model attempts to model the complex biology associated with heat gain and heat loss as well as accommodating all the factors that might influence an animal's heat stress threshold. This is far more challenging. Whereas heat stress can be measured (and to some extent calibrated) by monitoring the behaviour and physical appearance of the animals (e.g. panting score), heat load is far more conceptual and much

[1] *Note that for the sake of cohesion, these views have not been personally referenced.*

more difficult to measure. Consequently, the validation and/or refinement of the 'back end' of the model is a far more demanding task.

It should be recognised that the workings of the model are such that any miscalculation of either the heat gain/loss and/or heat stress threshold is quickly amplified and can easily lead to either a false alert or a lack of warning about an impending heat stress event. To assist in the review, the heat load modelling has been teased out into a number of headings. This facilitates a more detailed discussion of the issues involved as follows:

5.1.1 Heat load index (HLI)

The heat load index is an algorithm that has been designed to calculate the way in which the weather contributes to the likelihood of heat load, based on a number of weather parameters. In essence, the index reflects the cooling capacity of the air and/or immediate environment. It has no units but will range numerically from around 40 (at the lower end) to 100 (at the extreme high end). The HLI on its own does not indicate the likelihood of heat stress except in cases of an extreme heat event. It is designed to link the weather parameters to the concept of an accumulated heat load within the model.

The current index reads as follows (Gaughan *et al.* 2008):

When the black globe temperature (BGT) is greater than or equal to 25^{o}C…

HLI = 8.62 + (0.38 X RH) + (1.55 X BGT) + EXP (-WS + 2.4) – (0.5 X WS)

When the BGT is less than 25^{o}C…

HLI = 10.66 + (0.28 X RH) + (1.30 X BGT) – (WS)

Where:
HLI is the heat load index
RH is the relative humidity (%)
BGT is the black globe temperature (^{o}C) and
WS is the wind speed (m/sec)

Note that the index utilises a constant, then proportional factors for BGT and RH, followed by an exponential factor for wind speed (if the BGT is greater than or equal to 25^{o}C BGT). The greater emphasis on wind speed above 25^{o}C BGT reflects the fact that evaporative cooling via the skin is the heat loss mechanism over which the animal has the most control. This is engaged when required. As the heat challenge increases, the animal will respond by increasing peripheral blood circulation and initiating sweating. Wind speed then becomes more important to maintain both the temperature and water vapour gradients at the surface of the skin. This allows heat to be transferred to the air at the rate required.

When the index is used together with a weather forecast, the BGT is calculated by using a formula that factors solar radiation (see next heading). When the index uses actual weather information, the BGT is measured directly by the weather station equipment.

As noted by Sparke (Sparke 2008) an index should:

1. properly weight the factors involved.
2. accurately reflect the weather's contribution toward heat stress.
3. link effectively to the calculation of heat load.
4. make sense to end users.

Other relevant points that were identified during the course of consultation included:

- The current heat load index is generally considered to be acceptable.
- The earliest index (developed in 2000) utilised THI only.
- A subsequent heat stress model introduced the concept of THI hours to include the concept of heat load.
- There were several upgrades and iterations of the index over the following 8 years, that progressively included solar radiation, wind speed and the ability to incorporate a weather forecast.
- The current index factors both solar radiation (through the use of the BGT) and wind speed and provides the mechanism to factor heat load.
- The current index was determined scientifically by a method described in the 2008 Journal of Animal Science article (Gaughan *et al.* 2008).
- The consensus (industry pers. comm.) is that the model does a good job with wind speed, but may underestimate relative humidity.
- Although a simple heat stress index can be relatively easily calibrated from the point of view of the onset of heat stress, an index's effectiveness at lower temperatures is generally untested.
- An index that is linked to heat load will be more difficult to validate due to the myriad of factors involved in the calculation of heat load.

5.1.2 Black globe temperature (BGT)

The black globe temperature (BGT) is measured by a thermometer placed at the centre of a blackened sphere made of thin copper. It measures both temperature and radiant energy as a combined figure expressed as ^{o}C.

The BGT is currently determined using the following formula

$$BGT = 1.33 \times Temp - 2.65 \times \sqrt{Temp} + 3.21 \times \log(Solrad + 1) + 3.5$$

Where:

BGT is the black globe temperature (°C)

Temp is the dry bulb temperature (°C)

Solrad is the solar radiation (W/m^2)

Other relevant points that were identified during the course of consultation include:

- The BGT is not directly forecast but must be calculated by a formula that incorporates solar radiation (Solrad W/m^2) (see above).
- The BGT is, however, measured by the automated weather stations (AWS).

- The formula assumes an exposed animal surface area (since Solrad is expressed as W/m^2) and this may change during the course of the day (i.e. animals will have a greater exposure during the early morning and/or late evening) (Berman 2003).
- The current formula used to determine BGT would seem to underestimate BGT especially at higher BGTs (Katestone pers. comm.).
- Calculated BGT may differ substantially from measured black globe temperature using black globe thermometer since the black globe thermometer will usually register readings at night due to other forms of diffuse radiation whereas the calculated BGT assumes no solar radiation at night (Gaughan pers. comm.).
- An alternative way of calculating BGT using the Argonne method has been proposed by Katestone in the 2016 Progress report (Katestone Environmental Pty Ltd 2016a). This may be better suited for use in the heat load index.

5.1.3 Relative humidity (RH)

Relative humidity is a ratio of the amount of water vapour in the air compared to the amount water vapour that would be in the air if it were fully saturated (IUPS, 2013). It expressed as a percentage. The actual amount of water vapour in the air is referred to as the absolute humidity.

Since hotter air has a greater capacity to hold moisture, both air temperature and relative humidity should be considered at the same time. For example, at 40^{o}C, a cubic metre of air has the capacity to hold nearly 50 grams of water vapour when fully saturated. At 30^{o}C, a cubic metre of air has the capacity to hold only 27 grams of water vapour when fully saturated. This difference is the reason that hot dry air has a stronger cooling capability, and it can also complicate interpretation when air temperature and relative humidity are disconnected (as in the HLI model).

The wet bulb temperature combines both temperature and humidity and is a good indicator of the cooling capacity of the air, but air with a wet bulb temperature that is made up of a high temperature and low humidity, will have a greater cooling power than air with the same wet bulb temperature made up of lower temperature and higher humidity. This forms the basis of the THI index that was used by the feedlot industry in the initial heat load modelling.

Other relevant points that were identified during the course of consultation include:

- The current heat load index evaluates temperature and relative humidity independently when forecasting heat load and when utilising data from on-site weather stations. This can lead to inconsistencies if one is adjusted without an adjustment to the other.
- Relative humidity provides the fundamental link to evaporative cooling and is probably the most important factor in the calculation of heat load.
- Most measuring equipment (particularly those used in the on-site AWS) struggle to accurately measure high levels of relative humidity especially when the air is near saturation and significant errors can be expected.
- Relative humidity is the essential link in the Bowen equation (that dictates the likely avenue of heat loss and the amount of heat lost in each of the heat loss compartments).

- More recent research has favoured the use of a wet bulb globe measurement to assist in the measurement of heat load in humans (Budd 2008). It is not clear as to whether or not this measure can add value to the livestock industries but it is suggested that its suitability should be explored. It was also identified much earlier as having possible application. (Sparke *et al.* 2001).

5.1.4 Wind speed (WS)

Wind speed (WS) has a major bearing on the animal's ability to cool. Most animal's need a threshold wind speed to penetrate the coat. Additional wind speed helps to re-establish temperature and humidity gradients at the boundary layer of the skin's surface and facilitates the removal of heat from both convection and evaporation. This determines the rate at which heat is removed via the skin. The skin is engaged as a heat loss mechanism once the passive mechanisms such as normal panting are found to be inadequate to maintain homeopathy. Wind speed then becomes important when the environmental challenge forces the animal to engage the skin as a cooling surface. For the purposes of the heat load index, this threshold is considered to be 25°C BGT. Below this temperature, animals are thought to be able to shed heat with little effort and heat loss via the skin and heat loss via the integument is thought to be quite low. On this basis, two formulae are utilized in the heat load index. One formula is used when the BGT is equal to and/or below 25°C, and a different formula is used when the BGT is above 25°C.

Wind speed is also required to generally circulate air throughout the feedlot and allow the heat generated by the animals to be dispersed into the wider environment.

Other relevant points that were identified during the course of consultation include:

- The current index has a strong emphasis on wind speed (particularly when the BGT is greater than 25°C).
- If the black globe temperature is less than or equal to 25°C the index factors wind speed proportionally.
- If the black globe temperature is greater than 25°C the index factors wind speed exponentially.
- The choice of 25°C BGT is arbitrary, and whilst it does reflect an animal's comfort zone, it does not factor relative humidity. Consequently, it is not a true reflection of the environmental challenge, nor does it necessarily reflect the point at which an animal will engage the skin as part of its heat loss mechanism.
- This is not considered to be a major issue when it comes to calculating the accumulation of heat load since heat load will usually only be incurred when the BGT is well above 25°C.
- It may be an issue, however, when attempting to calculate the dissipation of heat load, since the formula determines the HLI which in turn dictates the extent to which the accumulated heat load is reduced.
- The influence of wind speed on the HLI at the lower temperatures is a critical part of the 'back end' of the model and begs further scrutiny.
- As stated earlier, the index's effectiveness at lower temperatures is generally untested and is much more difficult to validate.

- From a practical, computational point of view, although HLI may better represent the environmental challenge, it is not possible to use HLI as a cut-off point since it will lead to a circular reference (in its own calculation).

5.1.5 Determination of accumulated heat load (AHLU)

The AHLU records the number of hours that the HLI is above the upper critical threshold limit. The accumulated heat load is calculated by multiplying the time (hrs) by the difference between the actual (or forecast) HLI and the upper threshold value. These are added forward. This is considered to be better than a ‘spot’ measurement of the HLI, since it combines both intensity and duration of exposure.

The model assumes a HLI neutral zone whereby heat is neither gained nor lost from the animal, but if the HLI drops below the lower threshold level (assumed to be 77), the model assumes that heat is lost at a rate of one half the difference between the HLI and the lower threshold level. Furthermore, the model assumes that the rate of loss does not increase once the HLI falls below 50, and the rate of heat loss is assumed to reach a maximum of 13.5 accumulated heat load units per hour. This is described in the ‘Managing Summer Heat Workbook’ (Katestone Environmental Pty Ltd 2015c). Note that this differs from what is stated in the Tips and Tools (Meat & Livestock Australia 2006), which would appear to be in error.

An animal’s heat load will therefore either increase or decrease based on the above assumptions. A heat load of 50 accumulated heat load units is associated with high panting scores and is considered critical. Animals would be expected to be under severe heat stress, and may die, when the AHLU exceeds 100 units. The calculated heat load will be different for each category of livestock based on the setting of the upper HLI threshold. The setting of the upper threshold level is critical to the workings of the model.

The upper and lower HLI threshold levels, and the way in which the heat load is thought to accumulate and/or dissipate, were determined with as much scientific rigour as possible, as described by Gaughan (Gaughan *et al.* 2008), however it was always intended that they be refined by further work. At the end of the day the levels are still quite arbitrary and further work is required to validate the assumptions.

As stated previously, this is the ‘back end’ of the model that attempts to model the complex biology associated with heat gain and heat loss as well as accommodating all the factors that might influence an animal’s heat stress threshold.

A further challenge to the calculation of heat load is in instances where the HLI threshold factors may change during the course of the summer. For example, bedding class may fluctuate depending on the timing of manure removal. A method to deal with this has been developed (Katestone Environmental Pty Ltd 2015c) but it is complicated and few managers would make these adjustments on a continuous basis.

Other relevant points that were identified during the course of consultation include:

- Discussion around the biology of heat gain should consider metabolic heat, the heat generated by the digestion of feed and the heat generated by solar (and other) radiation.

- Discussion around the biology of heat loss should consider the various heat loss compartments (i.e. convective cooling via the respiratory tract, evaporative cooling via the respiratory tract, convective cooling via the skin and evaporative cooling via the skin). It should also consider any other methods of heat loss (e.g. conduction and/or any other possible heat sinks).
- The discussion should also look for any linkages between any calculated heat load and an increase in core body temperature and look at whether or not heat loss and heat gain occur equally in opposite directions.

There are many factors that influence an animal's stress threshold. Compared to the complexity of the biology of heat loss and gain, they seem rather straightforward. It should be noted, however, that a miscalculation of as little as one, in the determination of a threshold can lead to a completely misleading forecast if the heat load is sustained over a 48 or 72 hour period.

5.1.6 The HLI neutral zone

The HLI neutral zone is not the same as the thermo-neutral zone (TNZ). The TNZ is often central to the discussion of heat loss and heat gain. The TNZ, as described in the literature (Glossary of Terms for Thermal Physiology) (IUPS Thermal Commission 2003) applies to the zone between an upper and lower critical temperature in which an animal can maintain homeopathy with very little effort. It applies to a steady state in which an animal is not required to adjust its metabolic rate and/or engage in excessive panting or sweating to maintain its body temperature. It describes the animal's preferred temperature range.

The thermo-neutral zone, as described in the literature (da Silva and Maia 2013), refers only to temperature and does not consider either radiation, relative humidity or wind speed. The thermo-neutral zone also depends on the animal's acclimatisation since if an animal has adapted to colder weather by adjusting its metabolic rate and growing a winter coat, its thermo-neutral (comfort) zone will be different (Robinson *et al.* 1986).

The upper critical limit (UCL) described in the literature (Glossary of Terms for Thermal Physiology) (IUPS Thermal Commission 2003) does not refer to the point at which the animal takes on a heat load, but refers to a temperature below which the animal is comfortable. The point at which the animal might take on a heat load is actually referred to as T2 in the literature (da Silva and Maia 2013). At this point at which the animal is unable to shed sufficient heat to maintain its heat balance despite it having engaged all the heat loss mechanisms at its disposal. This animal is at risk of developing heat load and/or suffering from hyperthermia or heat stress.

If we apply this to the heat load model, we first need to factor radiation, relative humidity and wind speed in the determination of HLI. Secondly, we need to factor in acclimatisation if we are to determine a neutral zone. Thirdly, the T2 referred to in the literature actually becomes the upper HLI threshold as referred to in the heat load model (see the notes referring to Figure 1 in Chapter 6.1.1).

It is accepted that a heat load cannot be dissipated unless it has first been incurred. The concept of a negative heat load is valid but it would be incurred at the opposite end of the temperature range (T1) where the animal is losing heat despite it having engaged all the heat retention mechanisms at its disposal. This animal is at risk of hypothermia or cold stress. It does not necessarily follow, however, in either case, that there should be a zone where heat is neither lost nor gained once a heat load (either positive or negative) has been incurred. However, it may be that the change is too small to warrant calculating.

As stated, the HLI upper threshold is the point at which the animal is unable to shed sufficient heat to maintain its heat balance. At this point the cooling capacity of the air is insufficient to remove heat from the animal at a rate that exceeds its heat production despite it having engaged all the heat loss mechanisms at its disposal. However, if this cooling capacity increases (i.e. the HLI is lowered) and the animal continues to fully utilise all its heat loss mechanisms, it follows that a heat load could theoretically be dissipated quite quickly once the HLI subsides below the upper HLI threshold.

This is a grey area and it is acknowledged that an animal will engage its heat loss mechanisms both voluntarily and involuntarily. It is unclear as to whether or not the animal will actually fully engage all of its heat loss mechanisms in and around the lower HLI threshold. It is also acknowledged that there are many confounding factors, such as the time of feeding, diurnal fluctuations of core body temperature and behavioural changes.

The current workings of the heat load model assume that the animal neither gains nor loses heat load whilst the HLI fluctuates between the upper HLI threshold and the lower HLI threshold (nominally an HLI of 77). Furthermore, as stated previously, the model also assumes that when the HLI is below the lower threshold, heat load is dissipated at a rate of one half the heat load unit per hour. These settings are somewhat arbitrary.

The consultation undertaken during the course of this review suggested that the science associated with this area should be re-visited to better understand the dynamics of heat load dissipation. (Note that the industry has recently commissioned a study into the night time cooling of cattle which will address some aspects of this biology (Gaughan, B.FLT.0388, work in progress).

Other relevant points that were identified during the course of consultation include:

- The position of the HLI neutral zone (if found to be valid) may move with different breed types (it may be higher in *Bos indicus* cattle) (Gaughan *et al.* 2010).
- The position of the HLI neutral zone may vary during the course of a season (or in response to acclimatisation) (Robinson *et al.* 1986).
- The rate of heat loss at a very low HLI may be higher than currently factored and more comparable to the assumed rate of heat load (industry pers. comm.).
- The model assumes the lower HLI threshold to be fixed. There does not seem to be any science to support this hypothesis.
- The reference animal is described as a grain fed, healthy, black *Bos taurus* steer with a body condition score of 4+, and no access to shade (body weight is not specified).
- By definition, heat load occurs at the point at which core body temperature increases (IUPS Thermal Commission 2003; Maunsell Australia Pty Ltd 2003).
- A shift in core body temperature may provide an important benchmark from which it may be possible to better understand both heat load and heat dissipation. This may require the use telemetry in controlled heat rooms.

- A shift in core body temperature may provide the linkage to a nominated heat load (say 50 heat load units) and/or a panting score.
- Efforts to determine an energy value for a heat load unit should be encouraged.
- A study of this nature should also be able to measure enthalpy (the heat transferred to the air as it moves through the chamber) as the wet bulb rise (Maunsell Australia Pty Ltd 2003; Rodrigues *et al.* 2011).

5.1.7 The HLI threshold calculator

This is the most critical part of the heat load forecasting model. The sensitivity of the model is such that small differences in thresholds can amplify into big differences in heat load.

Loosely, the HLI threshold calculator is a tool that assists feedlot managers to assess the heat tolerance of every line of cattle in the feedlot. It is a key part of the pre-summer risk assessment program, and provides managers with a method to assess and re-assess the factors that influence heat tolerance as the season unfolds.

In regards to the heat load forecasting model, the HLI threshold calculator is used to attribute a heat stress threshold that is, in turn, used to predict or forecast a heat load event based on the concept of heat load. It must be re-emphasised, that the heat load forecasting model is highly sensitive to the setting of threshold levels. The use of weather station information to 'reset' heat load calculations does not lessen the sensitivity of the model to the threshold level.

If it were assumed that the model is accurate in the way in which it factors heat load and heat loss (i.e. in the 'front' and 'back end' of the model as discussed earlier) the model will accurately calculate the heat load for cattle at each heat stress threshold. If properly phrased, this statement becomes irrefutable. In this situation, the prediction of a heat stress event falls squarely on the accuracy of the threshold level.

In this 'magic wand' scenario it could be said that *"if the model is not working, then the user is not using it properly"* (in the sense that threshold levels are not being set accurately). Unfortunately, without further validation of the way in which the model assumes heat load and heat loss, it is not possible to make that statement with any level of confidence, and research into the 'back end' of the model is clearly an industry priority. Nevertheless, the setting of threshold levels is critical and efforts to better define and understand the factors that affect heat stress thresholds should be ongoing. This will allow feedlot managers to better determine threshold levels for each category of livestock.

Whilst the HLI threshold infers a level of risk, the actual risk is assessed against either historic weather data (in the case of the pre-summer RAP) or forecast weather (after the onset of summer). In both cases the risk is assessed against a predicted heat load based on the HLI threshold (not the HLI itself). As the shortcomings of the model become more recognised, there is an emerging case for the model to assess risk over an array of thresholds in a more detached manner, rather than attempting to precisely forecast a heat stress. This encourages the feedlot manager to be more intuitive in the way he allocates threshold levels to the various mobs of cattle within the feedlot and safeguards against an over reliance on the forecasts of the model. The ability of the feedlot manager to override the default values within the threshold calculator is testimony to this view. The importance of the factors that affect the heat stress threshold is not at all diminished in this scenario. With this in mind, the factors involved are discussed under the following headings:

5.1.8 Animal factors

There are a large number of animal factors to consider. In general, these factors are well understood, and mostly accompanied by supporting science (Sparke *et al.* 2001). For the most part, the weighting of the factors was determined by the initial work undertaken by Gaughan (Gaughan *et al.* 2008). Whether or not this science affords the necessary level of confidence is arguable. In some cases, the adjustment factor may simply be an industry estimate.

Breed type

The higher heat tolerance of *Bos indicus* cattle (as compared to *Bos taurus* cattle) has been studied extensively. It is supported by a large body of work over a long period of time. *Bos indicus* cattle are taller and narrower than *Bos taurus* cattle (at a similar weight) and consequently have a greater surface area due to their different body shape (rectangular prism vs a cylindrical prism). The presence of a dewlap (and even their larger ears) provide additional surface area that is well suited to dissipating heat. *Bos indicus* cattle have a lower metabolic rate (under similar conditions) and produce less heat. There are differences in the size and shape of the digestive tract and this influences dry matter intake. *Bos indicus* cattle have a much shorter coat length and have been shown to have very different skin characteristics that enables them to sweat more readily. This, and the greater surface area provide *Bos indicus* cattle with a much greater capacity to remove heat via the skin, and they are subsequently far more heat tolerant. These differences have been compared using the HLI model under research conditions in the USA (Gaughan *et al.* 2010). (N.B. Wagyu were not assessed).

The HLI threshold calculator offers the following divisions as criteria to categorise the genotype of cattle: *Bos taurus* (0), European (+3), Wagyu (+4) then 100% *Bos indicus* (+10), 75% *Bos indicus* (+8), 50% *Bos indicus* (+7) and 25% *Bos indicus* (+4) (ref. Table 2 - Tips and Tools) (Meat & Livestock Australia 2006).

Other relevant points that were identified during the course of consultation included:

- Breed type is considered most important factor when it comes to heat tolerance.
- There has been an abundance of work undertaken in this area, particularly on the difference between *Bos taurus* and *Bos indicus* cattle (Gaughan *et al.* 2010).
- It is difficult to calibrate HLI thresholds for *Bos indicus* cattle since they seldom become heat stressed.
- Wagyu cattle have shown themselves to be surprisingly heat tolerant (industry experience).
- European cattle are thought to be more tolerant than British breeds.
- Current assumptions for the different breeds are considered to be adequate.
- The level of confidence in these assumptions would be medium to high.
- Infused cattle can be judged on either phenotype or genotype.

- Phenotype is preferred, but some aspects of adaption would appear to be difficult to judge on visual appraisal.
- The level of confidence would be lower when trying to allocate a threshold adjustment for *Bos indicus* infused (e.g. 50% *Bos taurus:* 50% *Bos indicus*) cattle based on phenotype (reviewer's opinion).
- There appears to be differences between northern and southern cattle in which similar breeds are obviously much more heat tolerant when sourced from the North.
- This is considered to be a general toughness based on the environment (and not simply acclimatisation) (pers. comm. - industry meeting).
- It is possible that it has a genetic basis, but it is more likely to be environmental.
- Current adjustment factors appear to be well considered and reasonable but all require further validation, both at the high end (where heat load is incurred) and in the way that heat load is dissipated at lower temperatures (or lower HLI).

Days on feed

Days on feed is not, in itself a factor that should influence the heat stress threshold of an animal. It is, however, a proxy for both bodyweight and fatness. Both bodyweight and fatness are likely to increase with days on feed, particularly if the feedlot has a consistent production system with similar entry and turnoff weights.

New entrants are known to be more susceptible to heat stress due to the handling associated with induction and the stress associated with the novelty of their new surroundings. This would appear to be addressed in part, by acclimatisation, but it could also be addressed under this heading (or possibly under the heading of health status). Note that the reviewers encourage factors to be addressed individually and not merged.

Bodyweight is important since a bigger animal will have a lesser body surface area in proportion to its bodyweight.

Fatness affects the transfer of heat through the dermal and epidermal region by reducing conductivity and adding distance to the conduction equation. This reduces the animal's ability to move heat to the transfer surface at the boundary layer of the skin. This reduces the temperature gradients and affects the rate of heat removal.

The HLI threshold calculator offers the following divisions as criteria to categorise the days on feed: Days on feed (0-80) +2, days on feed (80-130) 0, days on feed (130+) -3 (ref. Table 2 - Tips and Tools) (Meat & Livestock Australia 2006).

Other relevant points that were identified during the course of consultation include:

- The visual assessment of fatness (body condition) is challenging when appraising animals in the pens and an averaging system is required.
- An easier way to factor bodyweight would also be required if it were to be considered in its own right.
- Days on feed may actually be required in the determination of acclimatisation.
- The criteria for days on feed are clustered, rather arbitrary divisions. Current divisions within the threshold calculator are lumpy (less than 80 days, 80-130 days and greater than 130 days).

- A more precise description of the assumptions behind the determination of body weight and assumed fatness (based on days on feed) could be helpful.
- A computer based, pen by pen, load plan approach may have application whereby pen information is pre-loaded and adjusted chronologically on a daily basis.
- It is difficult to attribute an accurate adjustment factor to days on feed due to a lack of clear criteria and the difficulties involved in visually appraising fatness and bodyweight.
- Whilst it is relatively easy to allocate a mob of cattle to one of the three 'days on feed' divisions described above, the linkages to factor that it is supposed to address (i.e. body weight, fatness and/or recent entry) are loose and lack prescription.

Acclimatisation

Acclimatisation is included in the heat stress threshold portal, however, it is not supported by any strong guidelines that assist in assigning an adjustment factor. It was included as a factor in the original work undertaken by Gaughan (Gaughan *et al.* 2008). It was then lumped together under a heading that included both sick and recovering cattle but has been more recently been removed as separate heading. (Katestone pers. comm.). Acclimatisation involves changes to the animal's metabolic rate (Robinson *et al.* 1986) as well as physiological (sometimes imperceptible) changes to the skin surface and the animal's coat (Barnes *et al.* 2004). Robinson demonstrated significant differences in the heat production from acclimatised versus non acclimatised cattle (187 kcal/kg$^{0.75}$/day (as measured) in non-acclimatised cattle vs 124 kcal/kg$^{0.75}$/day (as measured) in acclimatised cattle). This is a large difference. Acclimatisation may be important in setting both the animal's upper and lower HLI thresholds.

Acclimatisation may also explain a notable inconsistency that was highlighted at the industry meeting. It had been identified that the same cattle behaved quite differently when sent to feedlots in significantly different geographical regions. These cattle (assessed to have a HLI threshold of 86), when sent to Feedlot A, were reported to respond as predicted with visible signs of heat load being apparent when the AHLU reached 30 units. The same cattle when sent to Feedlot B, showed visible signs of heat load at very low levels of accumulated heat load (purportedly around 0). This inconsistency (with the assistance Katestone) was investigated. It showed that if the second group of cattle were allocated a HLI threshold of 83, the response was predictable. Furthermore, a precursory perusal of the HLI in the preceding 20 days showed that the Feedlot B cattle had a lower average daily HLI (primarily due to high wind speeds). This suggests that acclimatisation is a significant factor, not simply prior to entry, but also whilst the cattle are actually in the feedlot. It also highlights the need to develop a protocol to determine a climate history, presumably based on a daily HLI average (derived from the recorded hourly measurements).

The HLI threshold calculator offers only two divisions as criteria to categorise acclimatisation: Acclimatised (0), Non acclimatised (-5) (Katestone pers. comm.).

Other relevant points that were identified during the course of consultation include:

- Acclimatisation could be broken into three sections: pre-delivery, inception and then days on feed.

- Acclimatisation is a dynamic process that appears to happen over a medium term period (thought to be about 20 -30 days) (Robinson *et al.* 1986).
- It could also be determined by calculating a rolling average based on the daily average of the preceding HLI. Equally it could be linked to days on feed to factor pre-delivery and inception.
- This heading could also factor the susceptibility of new entrants due to handling procedures and the novelty of their new environment (although the reviewers suggest that it is probably better to keep factors isolated to allow more precise criteria to be allocated).
- Acclimatisation may explain many of the heat load forecasting inconsistencies identified by the industry.

Coat colour

Coat colour will influence the extent to which an animal absorbs solar radiation and is a major factor in heat tolerance. Coat colour has been shown to be a significant factor and was included in the original work (Gaughan *et al.* 2008). Other characteristics of the coat have a bearing on the extent to which the skin can shed heat. There are no criteria upon which to assess any coat characteristics other than colour. Coat length, the presence of mud or other contaminants can adversely affect the animal's ability to shed heat via the skin. As mentioned these are not currently factored in the HLI threshold calculations.

The HLI threshold calculator offers the following divisions as criteria to categorise coat characteristics: Black coat (0), red coat (+1), white coat (+3) (ref. Table 2 - Tips and Tools) (Meat & Livestock Australia 2006).

Other relevant points that were identified during the course of consultation include:

- Coat length (as mentioned) is probably equally as important as coat colour.
- There may be other less perceptible changes in the coat (other than length) that influence the insulation properties of the coat and/or the animal's ability to shed heat from the skin (e.g. rehearsed vasodilatory effects and the presence of fine hairs within the coat) (Barnes *et al.* 2004).
- Mud and other contaminants on the coats of cattle during recent heat stress events (e.g. Cyclone Yasi) have contributed to the mortality that was incurred.
- A wet coat is far more effective at shedding heat than a dry coat, provided that the relative humidity is not too high.
- A wind speed that penetrates the coat and allows heat exchange to occur at the boundary layer of the skin will reduce the effect of coat length on heat loss.
- The coat characteristics of *Bos indicus* are a major contributor to their heat tolerance. If this has already been factored by the breed effect, there could be a risk of double counting.

Health status

The HLI threshold calculator offers two categories, healthy or sick (and recovering). Note that earlier versions included acclimatisation but this factor has now been separated from this heading and is addressed in its own right. New entrants are known to be more susceptible due to the handling associated with induction and the stress associated with being introduced to new and novel surroundings. In the absence of any other home for a new entrant adjustment factor, new entrants could be either considered under this heading or under the heading of days on feed (or possibly acclimatisation).

Sick and recovering cattle are known to be more susceptible to heat stress (industry pers. comm.). In some cases, sick cattle will have an elevated body temperature as a symptom of their sickness. In other cases, sick cattle may lack strength and/or fatigue more easily, making them more susceptible to heat stress.

The HLI threshold calculator offers the following divisions as criteria to categorise health status: Healthy (0), sick or recovering (-5) (ref. Table 2 - Tips and Tools) (Meat & Livestock Australia 2006).

Other relevant points that were identified during the course of consultation include:

- The adjustment factor that is applied to this category of cattle is high (-5).
- This may be artificially high in a bid to encourage managers to keep a focus on sick pens and manage them accordingly.
- The extent to which these animals are more susceptible will depend on the nature of the sickness involved.
- These cattle represent a small, but significant, proportion of the overall feedlot population. It is probably not necessary to waste significant resources on calibrating or validating this particular adjustment factor.
- It is, however, another example of where the linkage between the HLI threshold adjustment and the factor itself is seemingly loose.

Other

There may be other factors that could be considered when setting HLI thresholds. One consideration may be that of exertion (or work) (Miller and Bates 2007). These are relevant in a theoretical sense because they provide a sense of how heat stress is addressed in other industries (or other species). The most recent human work takes an energy balance approach to heat stress, particularly in people who are required to balance exertion with the risk of heat stress (e.g. soldiers in Afghanistan).

Other relevant points that were identified during the course of consultation include:

- Work and exertion are significant factors in the study of human heat stress.
- Alternative approaches to addressing heat stress exist in the literature.

5.1.9 Site specific factors

Site specific factors will influence the pen microclimate. Some of these factors will be significant under certain conditions. Many of these are best factored more intuitively by the feedlot manager since they do not lend themselves to be incorporated into a simple computer interface.

Shade

There have been several key studies that demonstrates the benefits of shade (Binns *et al.* 2003; Byrne *et al.* 2005a; Gaughan 2008a, 2008b). Shade reduces the heat from solar radiation and therefore reduces the environmental challenge. Strictly speaking, it should be factored into the HLI and influence the determination of the HLI level. It is included as a threshold factor as a matter of convenience. It is expedient for shade to remain within the realm of the feedlot manager (since he/she knows which pens have shade). It is therefore included in the HLI threshold calculations. Shade is measured in terms of m^2 per standard cattle unit (SCU).

The HLI threshold calculator offers the following divisions as criteria to categorise shade: Shade (1.5 m^2/SCU – 2 m^2/SCU) +3, Shade (2 m^2/SCU – 3 m^2/SCU) +5, Shade (3 m^2/SCU – 5 m^2/SCU) +7 (ref. Table 2 - Tips and Tools) (Meat & Livestock Australia 2006).

Other relevant points that were identified during the course of consultation include:

- It is difficult (or impossible) for the heat load forecast service providers to know which pens have shade.
- The provision of shade has links to stocking density since it is important for all the animals in the pen to have access to shade if required.
- As with many factors, there are situations where an actual situation works to contradict the attributed adjustment factor. An example is where cattle bunch under shade in hot and humid and still conditions, and where bedding becomes moist. In this situation the microclimate under shade may actually be worse than in the unshaded areas, and if there is significant cloud cover, the benefits of shade may not compensate for the deterioration of conditions under the shade.
- The type of shade material used, shade design (shade height, slope etc.) may have subtle effects on the effectiveness of the shade provided. It is impossible to quantify the effect of all the shade and shade design permutations and combinations at this stage of the model's development (see 'Feedlot Shade Structures - Tips and Tools) (Meat & Livestock Australia 2006).

Feedlot design, pen orientation, drainage and/or the use of mounds

There are a number of other site specific factors that will influence the likelihood of a heat stress incident. Not all of them are easily quantified and/or converted into an adjustment factor. These include feedlot design and pen orientation. Feedlots that are designed to face prevailing winds will generally stay cooler than feedlots that are in the lee of substantial wind breaks. Prevailing winds will vary in direction and this may result in localised differences within a feedlot.

Drainage may differ between pens, and the site aspect is important when it comes to exposure to direct sun. Mounds are used in some feedlots to encourage air movement and eddies as well as provide drier areas within pens.

These factors are not currently included in the HLI threshold calculation.

Other relevant points that were identified during the course of consultation include:

- Most managers will intuitively factor many of the site specific factors when it comes to managing a feedlot to address an imminent heat stress incident.
- In some situations, these factors may reduce the accuracy of the heat load forecast since they influence events independently of the forecast.
- The extent to which the feedlot is set up with sprinklers and/or the ability to provide additional water troughs will influence the feedlot manager's choice of HLI threshold.

5.1.10 Management factors

The management factors are meant to relate to the aspects of management that influence the risk of heat stress. These remain discretionary. They differ from the mitigation measures that are triggered in the event of an imminent or occurring heat stress event.

Summer feeding strategy

A summer feeding strategy will consider such things as ration formulation, roughage content, time of feeding, frequency of feeding and managing dry matter intake. These are considered management factors. The summer feeding strategy does not feature in the HLI threshold calculator even though it is referred to in the Tips and Tools under 'Summer feeding of feedlot cattle'. The way in which a nutritional strategy can be used to reduce the risk of a heat stress event has been studied extensively (Mader *et al.* 1998; Mader and Davis 2004; Byrne *et al.* 2005a; Gaughan and Mader 2007; Kennedy 2008).

Other relevant points that were identified during the course of consultation include:

- A summer management plan may include a change of ration, used strategically to reduce the risk of a heat stress event.
- The summer ration differs from the heat stress ration in that it is designed to maintain production. By definition it will have a lower heat increment than the normal ration, but the caloric value of the ration (ME) may remain unchanged. It will generally be more expensive.
- This is different to the heat stress ration that may be triggered in the event of an imminent or occurring heat stress event. This heat stress ration will have a lower heat increment but this usually comes at the expense of ME.
- A summer feeding strategy will factor both risk and reward and will also depend on cause and effect.
- Ration formulation in feedlots is a highly refined business with the involvement of considerable expertise.
- The heat increment (HI) of the various feed stuffs is generally known and it should be possible to quantify the reduction in heat production.
- An exact linkage between the heat increment of the feed and the animal's heat balance is required to allow the HLI threshold calculator to accurately attribute a threshold factor to a summer diet.
- Note also that the heat generated by the digestion of feed will also be proportional to feed intake. Both the feed ingredients and the anticipated DMI should be considered.
- The heat increment associated with feeding is part of the overall energy balance. It influences the amount (and hence the rate) of heat that must be removed from the animal to maintain homeopathy and/or avoid incurring a heat load. If the heat

production is less due to a lowered DMI, this will allow homeopathy to be achieved at a lower HLI threshold. In this sense DMI is a legitimate HLI threshold factor.

- The accurate attribution of the adjustment factors involved would be aided by more explicit information regarding the heat increment of different feedstuffs.
- The heat associated with the digestion of feed is best studied in the context of an overall energy balance approach.

Water temperature

The watering infrastructure will vary between feedlots. Most water points are set up for sequential watering so that animals take it in turns to access water. Animals that are under heat load will often demonstrate polydipsia and polyuria (excessive drinking and urination). In this instance, there may be greater pressure on watering points and animals may bunch on the watering points making it difficult for some animals to access the water. Whilst this is a consideration, it is assumed that the watering infrastructure on all accredited feedlots is adequate.

Water temperature, however, is seen as an important HLI threshold factor. There are many good studies that point to the effectiveness of providing cold water to cool animals (EA Systems Pty Ltd 2004). Consumed water acts as a sink and allows heat to be dissipated from the animal. The effect of this is marked. In the context of attributing an adjustment factor to the HLI threshold, the effect is less clear.

Whilst the benefits of cooling water are not disputed, the biology associated with these benefits are complex. The extent of the benefit will depend on water consumption and will be limited by both the rate and amount of heat that can be transferred before the water is dispelled or (evaporated).

The HLI threshold calculator offers the following divisions as criteria to categorise water temperature: Trough water temperature of 15-20^{o}C (+1), trough water temperature of 20-30^{o}C (0), trough water temperature of 30-35^{o}C (-1), trough water temperature of greater that 35^{o}C (-2) (ref. Table 2 - Tips and Tools) (Meat & Livestock Australia 2006).

Other relevant points that were identified during the course of consultation include:

- Water consumption varies over the course of the day.
- It usually peaks a short time after feeding.
- Water temperature is linked to flow since it will often heat up if it lies idle in pipes (even if they are buried deep).
- Water temperature is usually lowest first thing in the morning.
- The criteria on how, when and where to measure water temperature is not clear.
- The biology associated with the benefits of cooling water has been documented (EA Systems Pty Ltd 2004), however, how this cooling effect links to an adjustment factor is not well explained.
- This heading does not include criteria to address water availability although both water temperature and availability are often discussed together. The reviewers counsel against addressing more than one factor under a single heading (to ensure that appropriate criteria are allocated).

Manure management

Under the terms accreditation, feedlot managers are obliged to maintain bedding in good condition. A manure management class is applied. The heat load model offers the same categories as those used in the accreditation process. Each has a different adjustment factor. The categories are: Manure management feedlot class = 1 (0), manure management feedlot class = 2 (- 4), manure management feedlot class = 3 (- 8) and manure management feedlot class = 4 (- 8). As noted in the Tips and Tools (Meat & Livestock Australia 2006), both the amount of manure and the water content impact on the likelihood of the manure pad to adversely affect the microclimate of the pen. The higher manure management feedlot classes are there to reflect the times when unpredicted events, such as heavy rain, have an immediate effect on the bedding class.

Other relevant points that were identified during the course of consultation include:

- The criteria associated with each class are described in the National accreditation guidelines.
- These refer mostly to manure pad depth and frequency of cleaning.
- A greater pad depth represents a higher risk should it be followed by high levels of precipitation.
- Pad moisture is probably overlooked somewhat in this description.
- Pad moisture is a major contributor to high relative humidity levels in the microclimate of pens.
- The types of ‘mud’ experienced in pens after extreme events is probably not included in the criteria of the national guidelines.
- A fatigue factor is often associated with these extreme events.
- Contamination of the coat is a common consequence of these conditions and this will compromise the cooling mechanisms at the surface of the skin.
- The original work conducted by Gaughan (Gaughan *et al.* 2008) used pad pack depth as the criteria.
- The industry research in this area appears limited (Watts *et al.* 2015).

Stocking density

The original work did not include stocking density as an adjustment factor (Gaughan *et al.* 2008), however it does appear as a factor in a later revision (Table 5 - page 14, FLOT.336) (Jackson and Killip 2006). It is not currently considered as a threshold adjustment factor and does not appear in the threshold table included in the latest Tips and Tools and does not feature in the RAP or the online TLI threshold calculator. Under normal circumstances stocking density is not thought to be a major factor, particularly when wind speeds are adequate to allow generous air movement around the animals. It is a bigger factor in enclosed livestock housing situations whereby heat production is directly related to the number of animals and heat removal is limited by mechanical ventilation. In the feedlot situation, stocking density plays a part when animals are expected to compete to access shade, watering points, mounds, or any other favourable positions within the pens. It is a factor when animals bunch together under very still conditions creating more extreme conditions in specific areas of the pen. A reduction in stocking density can alleviate pressure points and have a marked effect on animal comfort within the pens. The exact circumstances where this may be the case are hard to identify. It is difficult to quantify the effects of stocking density and incorporate the effects into an adjustment factor. Stocking density may influence DMI depending on the amount of trough space. The criteria are straightforward but the linkages may be less predictable. NFAS requires feedlots to provide sufficient space for each animal. These are described in the NFAS guidelines.

The divisions that applied to the additional space in the table referred to above are as follows: Additional 1.5-2 m^2 per head (+ 3) additional 2-3 m^2 per head (+ 5) and additional 3.5 m^2 per head (+ 7) (Jackson and Killip 2006).

Other relevant points that were identified during the course of consultation included:

- Stocking density may have lost favour as a HLI adjustment factor.
- May require more specific criteria and a better understanding of the circumstances whereby stocking density plays a part in heat stress.

5.1.11 Mitigation measures

This heading focusses on how mitigation measures are addressed by HLI threshold calculator. More detail on mitigation measures and how they are linked to heat load status level is provided under heading 5.3.5 (Setting of alerts and status levels). The mitigation measures considered by the HLI threshold calculator are distinct from the management factors. They should not be factored into the HLI threshold calculator but used to mitigate a possible, imminent or occurring heat stress event. The HLI threshold calculator can be used to undertake ‘what if’ calculations to determine the extent to which mitigation measures might avert a heat stress event. Mitigation measures include implementing the heat stress ration, placing additional water troughs in pens, the use of sprinklers, the strategic cleaning of pens with high manure accumulation and postponing or delaying the trucking and delivery of slaughter ready cattle. They are usually listed as part of the feedlot’s pre-determined EHL event management strategy.

Heat stress ration

A switch to a heat stress ration can be used to directly address an imminent or occurring heat stress event. It is a legitimate mitigation measure. However, a change to a heat stress ration has serious commercial implications and feedlot managers may be reluctant to make the change without significant justification. A change of ration may also impact on the operational efficiency of the feedlot, requiring many possible operational changes. These include changes to feed ingredients, changes to mixing and milling, changes to the time it takes to feed and changes to bunk management etc. (industry pers. comm.).

In a commercial sense, the decision to move to a heat stress ration will be balanced against an anticipated drop in dry matter intake (DMI). Both the heat stress ration and a lowered DMI will lower conversion rate and increase the cost of gain. Both have a significant impact on profit.

Welfare is obviously paramount and it is assumed that mortality is not factored into commercial decisions. The impact of the poor publicity associated with a heat stress event also has commercial implications of its own.

Understandably, the head load forecast has become pivotal to the decision-making process since it is an independent, tangible and auditable prediction based on industry guidelines. The decision as to whether or not to change to a heat stress ration remains the single most difficult decision to make over the summer period.

Other relevant points that were identified during the course of consultation include:

- Work that quantifies the commercial impact of lowered DMI would be useful to assist with the heat stress ration decision.
- Unlike the summer ration, the safer heat stress ration will generally have a lower ME and a higher roughage content (that limits intake). This has a big impact on feed conversion efficiency and profit.
- The mitigating effect of a heat stress ration can only be determined after considering both the heat increment of the feed ingredients and the anticipated DMI.
- Work that better quantifies the mitigating effects of a heat stress ration in the context of the overall energy balance would strengthen the linkage to the attributed threshold factor.

Additional water troughs in pens

The placement of additional water troughs in pens is promoted as a legitimate mitigation measure (as described in ‘Tips and Tools’) (Meat & Livestock Australia 2006). Animals that are under heat load will often demonstrate polydipsia and polyuria (excessive drinking and urination). In this instance the demands on the watering infrastructure may increase. Under these conditions, animals may tend to bunch on the watering points making it difficult for some animals to access the water. The provision of additional watering troughs in this situation may have merit. There is, however, a physical limit as to how many troughs can be installed in a short-period of time. It is a mitigation strategy, but it is probably limited to the neediest pens.

Other relevant points that were identified during the course of consultation include:

- Opinions on the value of additional troughs vary (industry pers. comm.).

The use of sprinklers

There has been some good work undertaken that demonstrates the value of sprinklers (Gaughan *et al.* 2003b; Gaughan *et al.* 2004). A method that sprinkles large droplets of water onto the body surface of the animals is considered to be the best method (Gaughan *et al.* 2003b). This boosts the capacity of animals to engage evaporative cooling on the skin surface, provided the relative humidity is not extreme. The use of misters is not recommended since, although they reduce the air temperature, they have little effect on the cooling power of the air. They may have application when the air is very dry and the added moisture does not compromise further cooling.

Other relevant points that were identified during the course of consultation include:

- The use of sprinklers may wet the manure pad and have a detrimental effect on the bedding.

- The strategic use of sprinklers at the hottest time of the day (when the relative humidity is at its lowest) may be the best strategy.
- The extent to which pens will be set up with the capacity to use sprinklers will vary from feedlot to feedlot.
- Although the use of sprinklers is considered a mitigation strategy, the capacity to use sprinklers in an imminent or occurring heat stress event could be viewed as a site specific factor that influences the HLI threshold (or at least influences the HLI threshold that a feedlot manager chooses for animals that have been stowed in these pens).

The strategic cleaning of pens with high manure accumulation

As a mitigation strategy, this applies to activity that is over and above the normal pen cleaning program. Activity may target specific areas where manure is known to accumulate, such as around water troughs, near feed bunks and/or under shade. Again, there may be a physical limitation on how much of this activity can be undertaken in a short time frame, but feedlot managers will know the areas within the feedlot that may be at the highest risk of 'wetting up' to the extent that they affect the microclimate within the pens.

Other relevant points that were identified during the course of consultation include:

- In a more general sense and as part of the feedlots accreditation, feedlot managers are already obliged to manage manure within a specified 'manure management feedlot class'.
- Feedlot managers may opt to be more vigilant about manure removal during the summer period as part of an overall summer management program.
- Manure removal is a costly and time consuming exercise, therefore, it will normally be undertaken on an 'as needed' basis.

The postponement of trucking arrangements

The feedlot production system is a highly integrated business with feeding operations programed to meet tight, pre-determined delivery schedules. Non-delivery can be very disruptive and lead to the closure of slaughter chains and/or costly adjustments on the part of the abattoir. Under extreme heat load conditions, cattle movement should be ceased.

- There is a great deal of pressure to honour delivery arrangements.
- There are compensating factors, since even if mortality is not incurred, dehydration and the higher incidence of dark cutters can involve significant loss. This has been well explained to receiving abattoirs (industry pers. comm.).
- More integrated feedlots that draw from different regions are better placed to manage delivery obligations.

5.2 Review of site specific weather forecasting

This section reviews the site specific weather forecasting. From the outset it should be noted that the site specific forecasting does not attempt to factor any influences that the feedlot itself may have on the local weather.

5.2.1 Site specific weather forecasting

Two forecasting models are evaluated. The first is the current model used by Katestone to provide the forecasting service. The second is an alternative model that has been identified as a possible replacement.

The current model

The Katestone heat load forecasting service utilises the Weather Research and Forecasting (WRF) model as its source of weather information. The WRF is a leading weather forecasting model developed by the United States National Centre for Atmospheric Research (NCAR).

The Katestone WRF (KWRF) is set up in the following way (Katestone pers. comm. and (Katestone Environmental Pty Ltd 2013b, 2014, 2015a, 2016b):

- The model receives its initial and boundary conditions from the Global Forecast System (GFS) with a 0.5 degree resolution. The GFS contains surface and upper air meteorological data assimilated from the Australian Bureau of Meteorology (BOM) monitoring sites, as well as satellite observations. GFS is a global forecast conducted by the National Centres for Environmental Prediction (NCEP) of the United States.
- The KWRF modelling domain extends from 105°E to 160°E and 8°S to 45°S including portions of the nearby oceans. The resolution of the model is 12 km and there are no nested grids. The forecast is for 7 days.
- Further observational data assimilation is not used in the KWRF. Observational data that could be assimilated includes BOM surface and upper data and/or the feedlot weather station data.
- KWRF incorporates a detailed land surface model that accounts for soil type, moisture content, porosity and vegetation type and density. Specifically, the land use data includes moderate-resolution imaging spectroradiometer (MODIS) satellite data, modified to Australian conditions. The land use data also includes a BOM dataset of soil moisture (that is reassessed every month or two).
- In KWRF, the recycling of the forecast from the previous day is not always on as error propagation can be problematic when it is on).
- The KWRF does not include any bias corrections.

After reviewing the KWRF model setup, the reviewers make the following comments:

- The use of WRF model is a good choice for the cattle heat load forecasting service, as WRF is a flexible and robust weather forecast model, widely used in air quality and climate applications and research.
- The KWRF model domain is sufficiently large to forecast weather for continental Australia and it is common to use GFS forecast to set the initial and boundary conditions of WRF forecast.
- Based on the industry feedback, the 7 day forecast is long enough for most CHLT users since the feedlot industry's main interest is in a 3-4 day forecast.
- It makes good sense not to include observational data assimilation in the model since the BOM observational data is already included in the GFS forecast data and the assimilation of observational data could exert an external shock to the system.

- The KWRF land surface model is appropriate. However, there is no evidence to suggest that it has been sufficiently fine-tuned to represent Australian conditions.
- The KWRF model grid resolution of 12 km is relatively course. Finer grid resolution generally produces a better localised weather forecast. It is recommended that the industry consider the use of a grid resolution of 6 km and a GFS forecast of 0.25 degree. The benefits of using a finer resolution are provided in Chapter 5.2.2.

An alternative model

The Australian Digital Forecast Database (ADFD) is an alternative weather forecasting product. It is a free service provided by the BOM. Information on ADFD is available on BOM website (http://www.bom.gov.au/weather-services/about/forecasts/australian-digital-forecast-database.shtml). Basically, ADFD contains official BOM weather forecast elements produced from multiple models. The weather elements available to the public include temperature, rainfall and weather types, presented in a gridded format and covering 7 days. The forecasts in the ADFD are quality controlled by the Bureau's operational meteorologists.

The reviewers have communicated with BOM on the technical aspects of the ADFD product, and consulted relevant peer-reviewed publications by Woodcock and Engel (Woodcock and Engel 2005) and Engel and Ebert (Engel and Ebert 2012) on the subject.

The general similarities and differences between ADFD and KWRF are summarised below:

- The ADFD and KWRF both cover a 7 day period and provide hourly data.
- The ADFD incorporates multiple models results, post model bias corrections and human forecast interpretations and in this way it is superior to the KWRF.
- KWRF is a single-model run, with no post-model corrections.
- The ADFD has a horizontal grid resolution of 6 km for most states, and 3 km for Victoria and Tasmania, finer than the KWRF's resolution of 12 km.
- Currently, the ADFD does not make solar radiation data available to the public, which makes ADFD data unsuitable for the calculation of heat load.
- BOM expressed no intention of providing free solar radiation data to the public in the near future; instead it is interested in a commercial pathway to make this happen.
- In comparison, KWRF provides solar radiation data and has the flexibility of producing a larger number of other weather elements.

Katestone conducted a review that compared the KWRF forecast to ADFD data for the 2015/2016 season on the 16 BOM reference sites (Katestone Environmental Pty Ltd 2016b). The comparison showed that ADFD performed better for temperature and relative humidity. This was consistent with Yussouf and Stensrud (Yussouf and Stensrud 2007) and Cui et al (Cui *et al.* 2012) who further confirmed that bias corrections generally improve the model accuracy for both surface temperature and humidity. Thus, bias corrections in the weather forecasts may have a place in future cattle heat load forecasting.

Bias correction would require KWRF to obtain BOM automatic weather station (AWS) data in real time for a large number of stations (not limited to the reference sites that have solar radiation measurement) and use them to correct the model biases. Feedlots AWS data would not be useful for such a purpose unless there were an independent quality assurance and instrument maintenance program. In summary:

There may be other forecast alternatives in addition to the BOM forecast, such as those produced by other weather forecast service providers. It is not clear how well these alternatives might compare to the KWRF since there is no evaluation data available for review.

5.2.2 Localized weather

Because the KWRF is limited by the grid resolution of 12km, localised weather events such as localised thunderstorms are not forecast well. The grid resolution may also affect the model's ability to forecast spatial variations of wind, temperature, and humidity produced by local terrain features and land use.

Furthermore, wind, temperature and relative humidity may differ significantly from the ambient environment due to influences of the feedlot itself. These cannot be forecast by any regional scale forecast models.

One option for improving the forecast of localised weather is to reduce the grid resolution. This option is widely used in weather forecasts if the resources are available. With smaller grid sizes, many of the localised terrain and land use features which cannot be represented by the coarse-grid model can be modelled correctly. However, with a large number of feedlots, reducing grid resolution would require significantly more computer resources.

Another option for improving the forecast of localised weather is to use bias corrections. To achieve this, recent AWS data from BOM can be used to calibrate the model forecast, with the underlying assumption that the AWS data is accurate for the local conditions and biases in recent forecasts are applicable to the forecast data. This would require an appropriate check of the quality of the raw AWS data.

The use of radar to retrospectively provide information on the past localised weather events has also been suggested. This could obtain more accurate recent rainfall data and better predict the subsequent relative humidity. The use of radar would be challenging. It would require BOM to provide a large data set of radar data, in real time, from a large number of radar stations around Australia. The national radar network may not have coverage at some feedlots. Further research would be required on how to incorporate radar data in the WRF weather forecast.

The localised forecast needs to be accurate in the sense of time as well as in the general sense of daily maximums or minimums. This is a different expectation to other end users whose requirements may be less precise. For example, if a cool change that is forecast to arrive by midday, does not arrive at the feedlot until late afternoon, then the HLI could be in excess of 10 units above a threshold for an additional 5-6 hours. This would result in an accumulated heat load of 50-60 units (even if the animal carried no heat load into the day). This would place that feedlot on false alert even though this scenario may not have been forecast. The converse may also be true. Thus it is important to continually improve the weather forecast (to an hourly basis), and reduce forecast errors.

In a similar way, it is important for feedlot managers to know whether the worst of the weather is still to come, or whether it has passed. This is challenging given the large number of sites involved.

5.2.3 Automated weather stations (AWS)

There are two sources of AWS data. The first is the AWS data measured by BOM and the second is the data measured by feedlots (onsite AWS). Currently no AWS data is assimilated into the WRF model. The BOM AWS data is indirectly used in the initial and boundary conditions of KWRF, since it is used by the GFS global forecast that initiates the KWRF.

Currently the onsite AWS data is used to forecast heat load as follows; The onsite AWS data is used to calculate the initial AHLU (denoted AHLU0) in the morning each day, around 6 am, before the forecast is issued. AHLU0 is calculated solely from the AWS data to initiate the forecast. HLI is then forecast each future hour, based on KWRF model output (with no post error corrections) for each feedlot location; AHLU (in the forecast) is expressed as:

AHLU (in the forecast) = AHLU0 + excess in (HLI1, HLI2, HLI3, ….)

where HLI1, HLI2, HLI3 … are HLI values for hour 1, 2, 3 …after the initiation time.

As discussed previously, AHLU is very sensitive to errors. Small errors are amplified by the model because of the way the model calculates the accumulation of heat load.

When AWS data is used as described above, the AHLU forecast is vulnerable not only to the forecasting errors in weather elements but also to any errors in the onsite AWS data. This is before the consideration of the errors that might be inherent in the model itself. Without vigorous quality control programs in place for onsite AWS, the integration of its data within the Katestone CHLT seems problematic. This was highlighted in the 2015/2016 forecasting season report and confirmed by communications with Katestone and comments received at the industry meeting held on 3rd June 2016.

A key part of the automated system for collecting onsite AWS data is the Heat Load Data Network (HLDN). Although automated, this is a deceptively complex network of connectivity that collects data from a range of sources. Some feedlots download data to the Katestone database directly. Other feedlots send their data to a hub (that is usually operated by the supplier of the weather station equipment) and the data is then sent to the Katestone database. In many cases there is a combination of wireless and internet connectivity involved. At each point, there is the potential for glitches to occur, and the unique nature of each connection makes it more challenging to build in automated systems to check on the quality of the data. Some service providers will calculate HLI and/or heat load independently, and this creates a challenge in terms of a consistent industry approach to the calculation of heat load.

5.2.4 Recent heat load forecasting season reviews

Katestone has conducted an annual review of the past summer season forecasts since 2004. In recent reviews (Katestone Environmental Pty Ltd 2013b, 2014, 2015a, 2016b), model results are compared to benchmark values, model methodologies are evaluated and model changes noted for the past season. User satisfaction was also canvassed using survey data.

The Katestone reviews provide a large amount of statistical data. They show that the HLI forecast has improved steadily in recent years when compared to the 17 BOM reference sites (i.e. those with solar radiation measurement).

The Katestone reviews provide statistical model performance data each year, for HLI, BGT, T (temperature), RH and WS at the BOM reference sites, and in the most recent report, at some feedlot locations. This data provides an insight in how the model forecast system performs. The model performance statistical data is compared to a set of model performance benchmark guidelines, which are listed below in Table1**.**

Table 1 - Forecast model performance benchmark guidelines extracted from the most recent review (Katestone Environmental Pty Ltd 2016b).

Measure	HLI	T	RH	WS
IOA	>0.9	>0.7	>0.7	>0.6
MAE	<6	<2	<10	<2
BIAS	±2	±1	±5	±1
RMSE	<6	<2	<15	<2

The Katestone reviews provide very limited references as why and how these benchmark values were chosen and what they represented, therefore we sought explanations and clarifications from Katestone on this subject. Our understanding as a result of this consultation process is as follows:

- The benchmarks for weather parameters (T, RH, WS) were based on Emery et al (Emery *et al.* 2001) whereby the benchmark values were derived from air quality applications. Since weather forecast for air quality applications is generally a single model run, these benchmark values tell us the sort of performance that can be reasonably expected from a single weather forecast model.
- The benchmark for temperature bias was increased from ±0.5° (as recommended by Emery et al, 2001) to ±1°.
- The benchmark values for RH may be derived from the vapour pressure benchmark values (to be confirmed).
- The benchmark values for temperature are applied to the BGT by Katestone. The relationship of BGT to solar radiation is ignored due to its none-linear nature. In addition, BGT is not measured at the BOM reference sites, and therefore BGT forecast values have no measurement data to compare with and therefore they were compared with the BGT values derived from the observed temperature and solar radiation measurement.
- The benchmark values for HLI were determined by Katestone. The HLI equation is composed of wind speed, BGT and RH. The benchmarks for the HLI were taken as the aggregate of the input parameters benchmarks. The sensitivity of the HLI equation to WS, BGT and RH shows that the allowable error in these parameters

equates to an error of 6-10 units in the HLI, therefore the MAE and RMSE is set to 6. The other benchmarks are set according to the temperature benchmark.

The reviewers note that the method to derive benchmark values for HLI seems sensible. Whether or not these guideline values for HLI are low enough to ensure meaningful results in AHLU is another matter. For example:

- the current benchmark values for the MAE and RMSE of HLI are six units. If the error of six units in HLI persists for six hours, errors in AHLU could be as high as 36 units. This is a very significant error.
- the current benchmark values for the bias in HLI are two units. If the bias of two units in HLI persists for one day, errors in AHLU could be as high as 48 units. This is a very significant error.

In this project, we have heard overwhelming concern that errors can rapidly accumulate in time, leading to unrealistic AHLU values. These concerns should be systematically documented by Katestone and supported by forecast data for different regions in Australia.

Although the Katestone reviews provide model performance statistical data for T, RH, WS, HLI and BGT, there is limited discussion about the results and how the data compared to the benchmark guidelines. Consequently, the Katestone reviews did not conclude what aspects of the model did well and what aspects should be improved.

During this review, the reviewers looked at the model performance statistical data more closely. A consistency in the bias behaviour was noted among HLI, BGT and T. For example, during the 2015/2016 season, for the Day 1 forecast at the 17 BOM reference sites, the biases in HLI were negative for 14 sites, and positive for 3 sites. The biases ranged from -3.07 to 0.54 units. For BGT, the biases were negative for 16 sites, and positive for one site, ranging from -1.20 to 0.10 degrees. For temperature, the biases were negative for 16 sites, and positive for one site, ranging from -1.13 to 0.11 degrees.

The above example demonstrates a consistency in the bias that would lend itself to correction. If biases in temperature forecast are reduced by post-WRF bias correction, the biases in BGT and HLI would be reduced accordingly.

Although the model performance statistical data in the tabular formats is useful, it is suggested that there may be better ways to present the information to an industry audience. A graphical representation of the tabular data may make it easier to draw conclusions about model performance. A map showing how the model performs for the different regions of Australia would be informative. It may also be useful to examine time series data to show how the model performs over the season and how the errors in weather parameters and in HLI propagate in time to lead to unrealistic AHLU.

The end of season survey results in the recent years were overall very positive. For example, the 2015/2016 season survey data showed that "96% of respondents were happy with the level of service this season". Valuable user comments were collected during the surveys, such as:

"Under 'no breeze', after storms and light winds, for non-shade pens, when pens were in need of cleaning" conditions, the risk can be significantly higher.

This pointed out the importance of forecast adjustments at the local level. Other comments read as follows:

> *"Most of the time, the temperatures/predictions were conservative compared to our own weather station; Temperature was usually a few degrees under other weather sites affecting HLI forecast; the forecast system underestimates RH and wind speed"*.

These comments point out that either the feedlot has a significant influence on the automated weather station data (in its own right) or there is a need to adjust the model for bias.

Although the overall user feedback was very positive, the user survey reporting did not point out the reforms or improvements that the cattle heat load forecast system needs in order to achieve better outcome.

5.3 Overview of the heat load forecasting service

This section looks more at how the heat load forecasting service is used. The feedlot manager will generally undertake a pre-summer review utilising the tools provided by the CHLT, followed by activity on an 'as required' basis over the course of the summer.

5.3.1 Pre-summer review

The pre-summer review has 4 components (as described in the Tips and Tools) (Meat & Livestock Australia 2006). They are:

1. To examine the feedlot site, its infrastructure, the feedlot management, the anticipated type of cattle and the number of days on feed.
2. Assess the feedlot's preparedness to manage an excessive heat load event.
3. Prepare a summer nutrition program.
4. Prepare an EHL event strategy.

Whilst the pre-summer review can be conducted without any web-based assistance, the Risk Assessment Program (RAP) helps to simplify the exercise and provide a systematic and logical way to work through the factors involved. Essentially it has two parts. The first is the HLI threshold calculator (as described earlier in the report), and the second is a set of historic weather data.

The RAP compares the risk factors determined by the HLI threshold calculator to the historic weather data and assesses the risk based on an anticipated accumulated heat load. The RAP allows feedlot operators to quantify the risk of an EHL event occurring at their feedlot. It can also be used to identify high risk pens within the feedlot and provides a 'what if' capacity to evaluate mitigation strategies (Tips and Tools) (Meat & Livestock Australia 2006).

Other relevant points that were identified during the course of consultation include:

- The pre-summer review is a key part of heat stress management.
- The RAP assesses risk against historic data based on load.

- There is some conjecture about the repeatability of historic weather to the extent that it produces heat load. There is a suggestion that the RAP should be simply compared to the HLI and/or heat stress threshold (industry pers. comm.).
- At first glance it might be felt that there is not a lot that can be done in the event of heat stress event. The ‘Managing Summer Heat’ workbook, however, outlines a strong list of potential actions that can be applied at each status level (possible, imminent and occurring) (Katestone Environmental Pty Ltd 2015c).
- The historic data used to assess risk in the pre-summer RAP should be updated (Katestone pers. comm.)

5.3.2 Effects of EHL on animal performance

Although efforts to avert an EHL event are usually driven by welfare considerations and the understandable wish to avoid mortality, it should be noted that EHL can result in significant production and performance losses (Tips and Tools) (Meat & Livestock Australia 2006). These are sufficient to justify a summer management plan in their own right. Apart from mortality, the effects may include a reduction in dry matter intake (with the subsequent effect on feed conversion efficiency and the cost of gain), effects on meat quality and an increase in susceptibility to disease (with the subsequent effect on morbidity) (Gaughan *et al.* 2013).

As discussed, feedlot operators may opt to move to a summer diet that moderates the animal heat load but maintains productivity. These rations are normally more expensive. Feedlot managers will often have a ‘heat stress’ ration that can be implemented when an EHL event appears either imminent or occurring. This ration will generally reduce productivity. Apart from the cost of the ration, there is often a considerable operational disruption involved in making changes, and this may incur significant (and sometimes hidden) additional cost.

Other relevant points that were identified during the course of consultation include:

- It would be valuable for the effects of EHL to be quantified and a commercial breakeven determined against the cost of making ration changes.
- DMI is recorded routinely on most feedlots. In many cases this information is integral to sophisticated in-house performance records.
- The linkages to heat load are not always obvious, particularly if the heat load does not develop into a recognisable heat stress event.
- Records that better associate (and document) the incidence of disease associated with a heat stress event would assist in determining this breakeven point.
- A breakeven that factors mortality is obviously not acceptable on animal welfare grounds.

5.3.3 Utilization of the heat load forecasting service

The heat load forecasting service involves a toolbox that consists of a number of tools and a number of services associated with each of these tools. These are difficult to strip down to small components because they are highly integrated within the overall service. However, this is attempted as follows.

The first facet of the heat load forecasting service is the location specific weather forecasting service. This has been critically evaluated and has been found to be as adequate as any other weather forecasting service working in isolation. The forecasting would be considered as a tool, but a feedlot could, if it wished, request this forecast to be delivered as a forecast of dry temperature, relative humidity and wind speed. This would be considered a service.

Also, if the feedlot wished, the forecast could also provide solar radiation and/or provide a forecast black globe temperature based on a suitable formula. The formula would be considered a tool and the calculation of the BGT would be considered a service.

The next facet of the heat load forecasting service would be the HLI index. This algorithm has been developed specifically for the feedlot industry in Australia and would be considered a tool. It can be used to convert the weather into a more meaningful, single value that reflects the weather's overall contribution to heat and heat stress. The HLI would be considered a tool and the calculation of the HLI value would be considered a service.

The HLI algorithm is designed specifically for the heat load model. Unlike other indexes like THI (that was used initially) and/or wet bulb temperature (which is used by the live export industry) the heat load model is focussed solely on heat load. The other indexes focus on a heat stress threshold, with a further adjustment for duration of exposure. Consequently, the heat load model has been developed around the HLI algorithm, and determines heat load based on a number of assumptions about the way in which heat load accumulates and dissipates. The model relies on both actual weather (to set the heat load) and forecast weather (to predict the likelihood of a heat load event). This model requires a threshold level against which to calculate the heat load. This model would be considered a tool and the calculation of heat load would be considered a service.

The information generated from the model can be presented in a number of ways and it is important for the industry to carefully consider the options. It is suggested that the simplest method is to calculate and display the heat load for each threshold level based on the actual weather experienced by the specific location (as generated from the forecasting services source data). This would be considered a service. This service could be extended to include a predicted heat load based on the forecast weather for the location. Again this would be considered a service.

A more recent facet of the heat load forecasting service is the ability for feedlots to utilize information from their own weather stations to reset the actual weather information. This supposedly calculates heat load more accurately for that particular location. This relies on the AWS information being credible and the equipment being properly maintained. The information generated from the AWS is fed back into the forecasting service data base through the HLDN. In some cases, this is achieved with a third party acting as a hub. Both the AWS and the HLDN would be considered tools (although the AWS would be owned by feedlot). The provision of a hub and the calculation and re-calculation of heat load for each threshold would be considered a service.

A further refinement of the service allows feedlots to specify a particular threshold against which to generate heat load alerts for a particular heat load threshold. Aside from the sick and recovering cattle (that are known to require special attention), the threshold is usually applied to represent the most vulnerable cattle in the feedlot. For this to be effective, it requires feedlot managers to accurately assess the vulnerability of their cattle. The HLI threshold calculator (as described earlier) assists feedlot managers with this task. The HLI threshold calculator is therefore a tool. Alerts can be sent in a number of forms (SMS, email etc.) to a range of phone numbers or destinations. Alerts for more than one threshold can also be generated. The sending of alerts would be considered a service.

Prior to triggering a heat load status change in a feedlot, a feedlot manager would most likely wish to confirm the threat and have the risk better defined. The forecasting service uses a computer interface to provide access to information that assists feedlot managers to make an informed response to information about whether or not to elevate the feedlot to an appropriate status. The computer interface would be considered a tool, however the maintenance of the site and the continual update of relevant information would be considered a service.

Other relevant points that were identified during the course of consultation include:

- As stated previously (and discussed again under the heading of conclusions) recent refinements have morphed the service from a management tool aimed at assisting feedlot managers to manage heat stress to a forecasting service that is expected to precisely predict heat load events in their feedlots.
- This has led to an excessive reliance on the service to predict heat load events and a tendency to underutilise the tools provided.
- Paradoxically the limitations of the model mean that the model cannot reliably predict heat stress in every circumstance and this has led, in some instances, to a sense of disillusionment with the service.
- Furthermore, in many instances the reasons for the inaccuracies are due to inappropriate setting of threshold levels and/or dysfunction of the AWS. These are outside the control of the forecasting service and often remain unresolved.
- This is regrettable since the power of service is in its management tools. The real power lies in the way in which the forecasting tools are used in the pre-summer review and in the constant re-assessment of all the relevant factors on a continuous basis all through the summer.
- To this extent the service has probably over-extended itself and it has been suggested that the service ‘pull back’ to a less exposed position until a better understanding of the biology involved allows the model to be more consistently accurate.
- Defining what constitutes a tool and what constitutes a service within the forecasting service is important to allow users to better understand the service they are receiving.
- This is important when considering a more tailored service that may suit a particular feedlot or end user.

5.3.4 Monitoring of animals and pen conditions

Cattle observations are key to recognising a heat load event. The three main factors are panting score, DMI and packed manure depth, but there are other behavioural signs. The link between panting score and body temperature has been further confirmed by recent work in central Queensland (Gaughan and Mader 2014). These include body alignment (to avoid solar radiation), shade seeking, increased time spent standing, crowding water troughs, body splashing, agitation and restlessness and reduced rumination, bunching (to seek shade from other cattle) (see 'Managing Summer Heat' workbook) (Katestone Environmental Pty Ltd 2015c). The industry has trialled an application that can be used on a hand held mobile phone. This has shown promise as an aid to the monitoring process.

Other relevant points that were identified during the course of consultation include:

- Daily monitoring of cattle is routine on most feedlots.
- In many cases this monitoring is casual (rather than formal)
- In other cases, it is part of formal operations (including comprehensive record keeping).
- Recording should be designed so that it is not so busy that it requires unnecessary time (especially when there is nothing happening) but is sufficiently detailed to provide both real time information and meaningful historic data (to later evaluate the effectiveness of heat stress management strategies).
- Panting score should be encouraged as the key measure of heat stress/load.
- Monitoring pen conditions is important at all times, with a view to triggering the cleaning of known problem areas as a precautionary measure when a heat load event has been forecast.
- The highly hygroscopic nature of manure can lead to a rapid deterioration of the bedding, particularly after heavy precipitation.
- A dry manure depth of 50mm has been suggested as a maximum pack depth level to avoid the risk of pugging and slurry.
- The mobile phone application has had limited success. It has had many teething problems and needs further work before it could be considered a viable tool.
- The application is less likely to be implemented in situations where it duplicates information.
- There is understandably some reluctance to merge information relating to DMI with production or feeding data that is central to the feedlot's feeding program.
- It has been suggested that in some situations there may be an excessive reliance on the forecasting system at the expense of the active monitoring of animals and pens (industry pers. comm.).

5.3.5 Setting of alerts and status levels

Alerts are used to assist the feedlot manager to determine a heat load status for the feedlot. The suggested status levels are normal, possible, imminent and occurring (Managing Summer Heat Workbook) (Katestone Environmental Pty Ltd 2015c). This enables the feedlot to structure its response in a systematic and repeatable way that is consistent with feedlot procedures. It encourages feedlots to pre-determine a list of practical actions that are ready to implement in response to each status level.

An alert level will usually be sent to a feedlot based on the cattle in the feedlot with the lowest HLI threshold. The alert levels are designed to be consistent based on the calculated and/or forecast accumulated heat load. This will usually be a AHLU event alert for today based on a predicted AHLU of greater that 50 or an AHLU event alert for tomorrow based on a predicted AHLU of greater than 50 for tomorrow.

There are three exceptions. The first is an alert based on a rapid HLI change (extreme event forecast). The second is an alert based on incomplete night time recovery (<6hrs of HLI below 77) and the third is an alert that relates to an extended AHLU event.

Other relevant points that were identified during the course of consultation include:

- Extreme events may generate an alert when the intensity of the environmental challenge is high but the AHLU is not excessive. The need for this was identified by Byrne (Byrne *et al.* 2006). This highlights the fact that that the index (and/or the model) in its current form, factors only heat load. It is beyond the capabilities of the current model to factor both intensity and duration (heat load).
- The alert is referred to as a 'rapid HLI change' alert since a slower onset will usually be picked up by the heat load calculations. It therefore applies mostly to cattle that have not been previously subjected to heat load.
- The alerts based on a time effect (extended AHLU >50 for 3 consecutive days) and incomplete night time recovery (AHLU = 0 for less than 6 hours for more than 3 consecutive days) are both examples of where an alert has been introduced to compensate for a perceived deficiency in the model. This highlights the need to better understand the biology around heat gain and heat loss.
- If a feedlot is receiving too many or too few alerts it is probably because the HLI threshold setting is not correct. If this is the case, feedlot managers are encouraged to reassess their HLI thresholds. It is not suggested that the AHLU upon which the alert level is set be changed (i.e. the AHLU alert level should be maintained at >50).
- The assignment of heat load status, in response to the alert, links a forecast to actions and encompasses more than a simple alert issued by the heat load forecasting service.
- The assignment of heat load status encourages the forecasting service to be used as a tool rather than a definitive predictor of a heat stress event. It uses a pre-determined action plan to trigger mitigation activity.
- It is noted that alerts are forwarded with an explanation as to what it is that has triggered them. This is important since a manager's first task will be to investigate the alert to, firstly confirm it to be real, and secondly to determine the nature of it. This involves both assessing what is happening in the feedlot as well as investigating the data that has contributed to the alert. At this time the feedlot manager will be seeking as much information as possible.
- Whilst the forecasting service will seek to minimise the amount of information forwarded to the feedlot when heat load is not forecast, there is a case for a second tier of information to be available if required in the advent of an alert.
- Users become accustomed to a certain interface, so providing a second tier would require careful consideration. A second tier would follow a sequence of questions that firstly confirm the threat and secondly describe the risk and provide all the information necessary to make responsible decisions to elevate the feedlot to an appropriate status.
- There is currently no formal feedback loop in place whereby the forecast (or non-forecast) of an event is validated. This places the forecasting service in an invidious position whereby they are being expected to improve the service without knowing when or where the forecasts have been inaccurate. For the industry to go forward, it

will need to provide detailed feedback that enables aspects of the forecast to be quickly and effectively investigated.

5.3.6 Web site design and industry interface

The Katestone website is central to the overall heat load forecasting service. There are two aspects to the website. The first is the interactive portal that allows feedlot managers access to the tools of the CHLT. The second part of the website is the information conduit (HLDN) that is used to store and share forecasting information and the information received from the AWS. Users have only access to the interactive portal. Information on the likelihood of a heat load event is sent as an alert.

Other relevant points that were identified during the course of consultation include:

- It is generally considered that the current interface is too busy and should be stripped back (industry pers. comm.).
- An alternative view suggests that it may be better to wait until more is known then change it when industry knows better what it wants (industry pers. comm.).
- It has been suggested that a single line plot to depict heat load has merit and better demonstrates the onset of heat load (industry pers. comm.).
- It has also been suggested that a ‘spinner’ that is used to click through different HLI threshold values would provide a better ‘feel’ for the situation, and provide a more detached service (industry pers. comm.).
- The general feeling is for there to be less information when not much is happening, but the ability to quickly dig deeper if more detail is required.
- Managers need to quickly determine whether or not an alert is real, the nature of it, and whether or not the information generating the alert is credible.
- In keeping with an overall approach, it is suggested that efforts be made to ensure that statements that are made by the forecasting service (in regards to forecasting) are irrefutable.

The website can be accessed at the following web address: http://chlt.katestone.com.au/

5.3.7 Technical support and extension

Workshops have been conducted that support the industry approach to forecasting heat load. This has been well received and productive. It also provided the opportunity for the forecasting service providers to get valuable feedback from the end users and to gauge the extent of buy in and uptake of the service overall. There is a place for service providers to make ‘technicians’ available to get closer to feedlots, especially if the service becomes more tailored. These same technicians would be in a position to inspect AWS and the functionality of the HLDN. Some of these roles could be packaged with research that helps to validate the model.

5.3.8 Continuous improvement and/or research and development

The existing service providers have shown a strong commitment to the industry heat load forecasting. It is possible that they have over-delivered due to strong sense of ownership and genuine interest in the subject. At the same time, there is a need for better definition of what is deemed to be part of the service, the extent to which the service is expected to be involved in continuous improvement and what constitutes additional research and development.

5.3.9 Regulatory support

The heat load forecasting service is supported by the industry accreditation program (AUSMEAT 2006, 2013, 2015). Accreditation requires that a feedlot systematically assesses the summer heat load risk. The exact wording in the NFAS accreditation standards (ELEMENT LM5) is contained in the appendix. Although not mandatory, engaging the Katestone heat load forecasting service essentially meets these obligations.

6 Discussion

6.1 Key points of contention

The reviewers note that the industry currently has taken a pragmatic view of the heat load forecasting service and sees it very much as a work in progress. The industry has a strong sense of ownership and is tolerant of the fact that limitations and shortcomings may exist. There is, however, quite healthy debate around many facets of the service. These fall under three main headings.

6.1.1 Explaining inconsistencies in forecasting

There are many possible reasons why inconsistencies occur. For the most part, the inconsistencies that have been investigated have shown the reasons to be related to technical glitches or misinterpretations. Certainly, all of the inconsistencies examined by the reviewers were of this nature. Examples include; a situation where a weather station submitted a zero wind speed over a period of three days pointing to a malfunction of the anemometer. Another example identified a situation whereby an alert was not issued, but where subsequent investigation showed that the model would have predicted an event had the threshold been set lower, suggesting that the threshold had been set inappropriately. A further example identified that a feedlot staffer had simply confused HLI with AHLU leading to an apparent discrepancy. This apparent inconsistency was quickly resolved once the reason was pointed out.

These examples support the suggestion that the industry should establish a strong feedback loop to allow inconsistencies to be quickly and effectively investigated. In the absence of this, it is quite likely that the model (and/or service) will be judged to be not working when in fact the problem is more about education and extension rather than the shortcomings of the model.

Notwithstanding the above, it is widely accepted that the model has shortcomings and there is no doubt that some inconsistencies will be attributable to the model itself. Some of these have been identified earlier in the report. They include the need for forecasters to calculate

BGT from predicted solar radiation using a formula with known errors, the difficulty in finding equipment that is able to accurately measure high levels of relative humidity and problems with weather station measurement of wind speed. These are important issues and they should be addressed where possible, however, they are somewhat peripheral to the central construct of the model.

The HLI model

The initial focus should be on the central construct of the model. This refers to both the ‘front end’ and the ‘back end’ of the model as described earlier in the report. The construct of the model therefore includes the algorithm used to calculate HLI as well as the method used to calculate heat load. As a way of illustrating the factors that affect the workings of the model, the reviewers include a diagram that depicts the assumed rate of heat dissipation from an animal under heat load (Figure 1 – page 53).

The first point of reference is the assumed rate of heat production. Estimates vary within the literature but a rate of 640W has been assumed in this case (1.6W/kg for a 400kg animal) (Maunsell Australia Pty Ltd 2003).

The next point of reference is the HLI neutral zone. In the model, this runs between the lower HLI threshold (where the HLI = 77) to an upper HLI threshold (where the HLI = 86) as shown in the figure (also referred to as T2 as explained in Chapter 5.1.7). As explained earlier, the position of the HLI neutral zone may vary depending on such factors as breed type and/or acclimatisation. The current model assumes the lower HLI threshold to be fixed, and adjusts the upper HLI threshold depending on the HLI adjustment factors (as determined by the HLI threshold calculator).

The model assumes that there is no nett gain or nett loss of heat load within the HLI neutral zone. In actual point of fact there is probably a central point (say HLI = 81.5) whereby the capacity to lose heat is equal to the rate of heat loss required. Around this, the reviewers suggest that there is probably a slight gain or slight loss, associated with the small changes to the cooling capacity of the air and the gradients involved in cooling. For the purposes of the model, however, the heat gain/loss throughout the HLI neutral zone is assumed to be zero.

This is only part of the story, however, since what is described above refers only to the cooling capacity of the air. The animal has, at its disposal, a host of physiological (or biological) responses that it can engage to combat a heat load challenge. What is normally seen is that the animal will engage these proportionally as the HLI challenge increases (industry pers. comm.). The response when the HLI decreases is much less clear. From a theoretical point of view, if an animal fully engages all of its heat loss mechanisms, and the cooling capacity of the air increases (in keeping with a falling HLI) the animal should lose heat immediately in keeping with the gradients involved.

As the HLI increases, the reviewers suggest that cooling capacity of the air becomes compromised to the point where the rate of heat loss can no longer keep up with the rate of heat loss required and the animal takes on a heat load. The rate of heat loss diminishes as the gradients are eroded, to the point where at some stage, the air loses its capacity to achieve any sort of cooling and the rate of heat loss approaches zero (i.e. if the air temperature is the same as body/skin temperature (38.6^{o}C) and the relative humidity is

100%). This is supported by the calculation of HLI whereby, if there is no solar radiation and a healthy breeze of 6m/sec, the HLI equation delivers an HLI of 101.09 at this point. For demonstration purposes, the reviewers have assumed this point to be an HLI of 100.

Whether or not the animal actually keeps its heat loss mechanisms fully engaged is the point of conjecture, particularly since there are both involuntary and voluntary components, both of which respond to a hierarchy of needs. This is important since it dictates the rate of heat loss. Note that the model assumes heat load is dissipated below a lower HLI threshold of 77 at the rate of half of which it is incurred above the upper HLI threshold (up to a maximum of 13.5 AHLU/hr). Consequently, although the assumptions around heat load accumulation are well supported, the big question is what happens when going the other way (i.e. heat load dissipation).

This question is somewhat addressed by the terms of reference of a project (B.FLT.0388) which will evaluate the factors that affect night time cooling. However, it may not fully address all the outstanding questions about cooling within the model.

As stated earlier, the aim of the figure is to illustrate the factors that might affect the workings of the model. For example, in regards to breed type, the genetic adaptations of *Bos indicus* cattle allow them to shed heat far more easily than *Bos taurus* cattle. In all likelihood, this would move the HLI neutral zone to the right (in the figure provided). However, the HLI = 100, when disregarding solar radiation, is fixed by the cooling properties of the air so that the angle of decline that represent the rate of heat load would be steeper than the one shown in the figure. However, since *Bos indicus* have a lower metabolic rate, the assumed rate of heat production would be lower and therefore the lower uppermost part of the HLI neutral zone (to a lower position on the vertical axis). This would moderate the steepness of the graph. There is also a suggestion that the lower HLI threshold should move in keeping with any shifts to the upper HLI threshold (Gaughan *et al.* 2010).

Acclimatisation would influence the shape of the graph in a similar way. Non acclimatised cattle, moving to a hotter environment will produce more metabolic heat. This will raise the uppermost part of the HLI neutral zone (to a higher position on the vertical axis). The physiological changes to the skin coat reduce the animal's ability to dissipate heat and would most likely shift the HLI neutral zone to the left.

As mentioned, days on feed are a proxy for both fatness and bodyweight. Both these factors limit the extent to which an animal can dissipate heat, and this would most likely shift the HLI neutral zone to the left.

Sick and recovering cattle are also compromised in the way in which they can dissipate heat. This factor would also shift the HLI neutral zone to the left.

Solar radiation affects the workings of the model in quite a different way. It is suggested that solar radiation adds significantly to the amount of heat that must be dissipated, but because solar radiation is a component of the HLI, the cooling power of the air at any given HLI will be greater. Consequently, although solar radiation will raise the uppermost part of the HLI neutral zone (to a higher point on the vertical axis) it will also allow the HLI to increase significantly before the cooling capacity of the air approaches zero (possibly to as much as HLI = 120).

The resultant shape of the graph would therefore run parallel to the existing shape. Coat colour and shade would mirror solar radiation. They both reduce the effects of solar radiation and therefore the amount of heat that needs to be shed. This would modify the shape of the graph accordingly.

Water temperature helps the animal cool by acting as a heat sink. It has no bearing on the cooling capacity of the air, and therefore would mirror reduced heat production in the figure provided.

Manure management is a special case and is important due to the potential for it to significantly increase the relative humidity of the micro-climate within the pens. Ultimately this affects the cooling capacity of the air and therefore would most likely shift the HLI neutral zone to the left. It might also shift the point at which further cooling can be achieved (i.e. HLI = 100 to some lower value of HLI).

Summer feeding, utilising a ration with a lower heat increment, will reduce heat production and therefore lower the uppermost part of the HLI neutral zone (to a lower position on the vertical axis).

Stocking density is slightly more complicated since it influences access to shade, water and feed troughs. It also influences the flow of air through the pens. It is not, therefore easy to illustrate within the model.

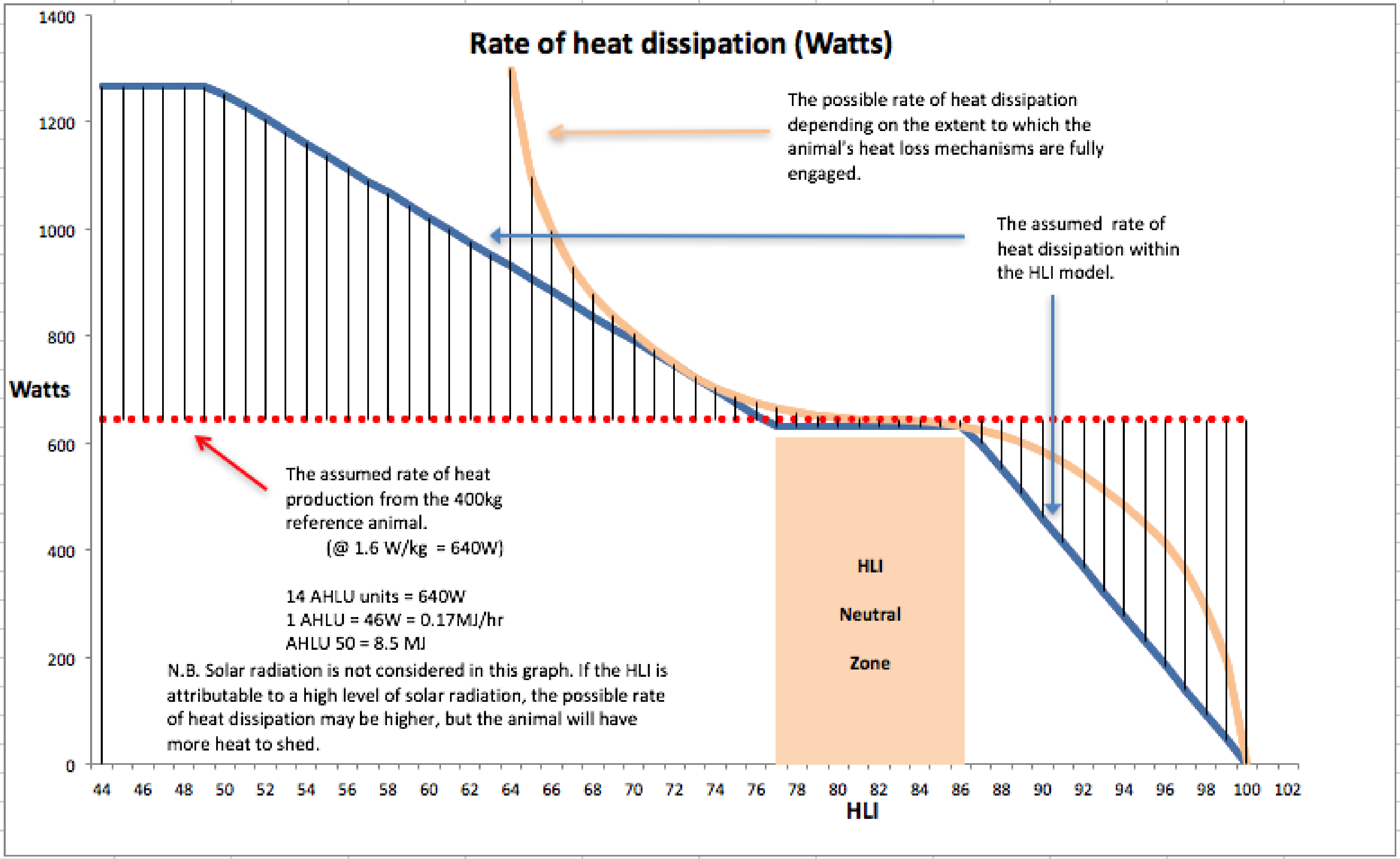
The purpose of this discussion is not to be too exact about the dynamics of heat gain and heat loss, but to illustrate that, although the adjustment factors have been determined scientifically through regression analysis, this determination is still a long way short of the sort of validation that is required for a full understanding of the biology involved.

Quantifying the energy value of a single heat load unit

There is a further point of reference. If the rate of heat dissipation is zero at HLI 100 = 0 (because the air has lost all its cooling power) and the upper HLI threshold is 86, then the rate of heat load at HLI = 100 is 14 AHLU per hour. Since there is no heat loss at this point, 14 AHLU equals the heat production from the animal, therefore 14 AHLU would equal 640W. One AHLU can then be quantified as 46W or 0.17MJ/hr. Based on this assumption, an accumulated heat load of 50 units (AHLU 50) would be equivalent to 8.5 MJ energy.

This determination should be subjected to more scrutiny, but if it holds, it provides a pivotal link to a more sophisticated energy balance type approach that could determine the required rate of heat loss in each of the heat loss compartments (Thompson *et al.* 2014).

Figure 1. – Showing the assumed rate of heat dissipation from an animal under heat load.



The HLI threshold factors

The HLI threshold factors have already been discussed in some detail in the Results section. For the purposes of further discussion, the same factors are evaluated under the headings of criteria, linkage, validation and exceptions and presented in the following tables (Table 2a-2d). These headings place a greater focus on the underlying science behind each of the factors and examine the way in which each factor is assessed. This highlights the possibility that an HLI threshold adjustment factor may be inappropriately applied. A level of confidence is applied to the way in which each of the factors are assessed.

Table 2a. - Showing the key characteristics of the HLI threshold adjustment factors

Factor	Criteria	Linkage	Validation	Exceptions/inconsistencies
Breed type	*Bos taurus* (0) European (+3) Wagyu (+4) then…. 100% *Bos indicus* (+10) 75% *Bos indicus* (+8) 50% *Bos indicus* (+7) 25% *Bos indicus* (+4)	The difference between breeds in regards to heat tolerance is well understood.	Assessed in the original work (Gaughan *et al.* 2008). Assessed subsequently in a scientific framework using HLI (Gaughan *et al.* 2010). Confidence level: Medium – high.	Wagyu (in small numbers) were assessed in original but not assessed by Gaughan in 2010.
Days on feed	0-80 (+2) 80-130 (0) 130+ (-3)	Days on feed are considered a proxy for bodyweight and fatness. The linkages involved would be considered loose.	Assessed in the original work (Gaughan *et al.* 2008). No further validation work has been undertaken. Confidence level: Low.	Inconsistencies could be expected if initial bodyweight and/or fatness were out of the ordinary and/or if cattle are being fed for different purposes. New entrants may confound this adjustment factor.
Acclimatisation	Acclimatised (0) Non acclimatised (-5)	The biology of acclimatisation is well understood, however, the linkage to the HLI model and the way in which it might move the HLI neutral zone has not been properly determined.	Acclimatisation was assessed in original work (Gaughan *et al.* 2008), but then included with sick cattle, only to be removed recently as a factor in its own right. No further validation work has been undertaken. Confidence level: Low	Coat length could also be considered as should any changes to the make-up of the coat in response to adaptation. Changes to metabolic heat production will have profound effects on the overall energy flux equation and the position of the HLI upper and lower thresholds.

Table 2b. - Showing the key characteristics of the HLI threshold adjustment factors (continued).

Factor	Criteria	Linkage	Validation	Exceptions/inconsistencies
Coat colour	Black coat (0) Red coat (+1) White coat (+3)	This linkage refers solely to the degree to which coat colour influences the absorption of solar radiation. This heading does not address any other coat characteristics.	Assessed in the original work (Gaughan *et al.* 2008). No further validation work has been undertaken. Confidence level: Medium.	This heading is only valid if the HLI is attributable to some level of solar radiation. If the weather is overcast, there may be no need to make an adjustment for coat colour.
Heath status	Healthy (0) Sick and/or recovering (-5)	This linkage refers directly to sick and/or recovering cattle.	Assessed in relation to a large population in the original work (Gaughan *et al.* 2008). Confidence level: High.	Industry experience is consistent with this factor and the weighting of this adjustment factor encourages the extra vigilance required for this category of cattle.
Shade	1.5-2 m^2/SCU (+3) 2-3 m^2/SCU (+5) 3-5 m^2/SCU (+7)	The benefits of shade has been well researched and the linkages are well understood (Binns *et al.* 2003; Meat & Livestock Australia 2006; Gaughan 2008a, 2008b).	Assessed in the original work (Gaughan *et al.* 2008). Confidence level: Medium - high.	Shade is only of benefit if solar radiation is a component of the HLI. A contradiction can occur under cloudy conditions where the environment under shade is considerably more humid than out in the open pen.

Table 2c. - Showing the key characteristics of the HLI threshold adjustment factors (continued).

Factor	Criteria	Linkage	Validation	Exceptions/inconsistencies
Water temperature	15-20°C (+1) 20-30°C (0) 30-35°C (-1) 35°C (-2)	The influence of water temperature is well understood; however, the linkage is not strong since water temperature is not measured on a continuous basis. This heading does not address water availability.	Assessed in the original work (Gaughan *et al.* 2008). Identified in earlier industry work (EA Systems Pty Ltd 2004). Confidence level: Low	Water availability is an important factor. Water temperature will vary over the course of the day. Water temperature will vary depending on demand.
Manure management	Manure management feedlot class = 1 (0), manure management feedlot class = 2 (- 4), manure management feedlot class = 3 (- 8) and manure management feedlot class = 4 (- 8).	The industry is well aware of how high pad moisture, and the deterioration of the manure pad can affect heat load and contribute to heat stress. Despite this, very little formal work has been undertaken. Contamination of the coat is a common consequence of poor bedding conditions and this will compromise the cooling mechanisms at the surface of the skin.	Assessed in the original work (Gaughan *et al.* 2008), however the original criteria related to pad pack depth. Confidence level: Low - Medium.	The manure pad can deteriorate very quickly under adverse conditions. NFAS requires that the pad be kept in good condition at all times. Feedlot manager would be likely to factor bedding conditions based on daily conditions and the localised experience.

Table 2d. - Showing the key characteristics of the HLI threshold adjustment factors (continued).

Factor	Criteria	Linkage	Validation	Exceptions/inconsistencies
Summer feeding	Not currently evaluated as an adjustment factor.	This factor refers to a summer diet with a lower heat increment (not the heat stress diet used when a heat stress event is imminent). The industry has completed a number of studies that explore how dietary strategies can reduce heat load (Kennedy and Cronje 2005; Kennedy 2008).	Summer feeding was not assessed in the original work (Gaughan *et al.* 2008). Earlier work was undertaken that showed how heat stress could be managed through nutrition (Mader *et al.* 1998; Mader and Davis 2004; Gaughan and Mader 2007). Confidence level: Low – medium.	The heat produced by the digestion of food is an important influence on the overall energy balance equation. DMI has a strong influence in its own right. High intake (after a period of lowered intake) is a major contributor toward EHL. Despite the amount of good work that has been completed, the way in which nutritional management links directly to the heat load model remains unclear.
Stocking density	Not currently evaluated as an adjustment factor.	Stocking density becomes important when access to pressure points becomes limiting. This applies to feed bunk space, access to shade, access to water and/or access to preferred position within the pen. These linkages have not been formally addressed by the industry.	Stocking density was not assessed in the original work (Gaughan *et al.* 2008). It was later included as an adjustment factor (Jackson and Killip 2006) but has since been removed. Confidence level: Low.	If stocking density limits access to feed and depresses DMI, this may have a confounding effect. Intake in this situation would likely be uneven throughout the mob.

Site specific weather forecasting

As stated previously, Katestone utilises the Weather Research and Forecasting system to forecast the weather. Better systems exist but they do not predict solar radiation, making them unsuitable for use within the heat load forecasting model. The lack of resolution associated with this system and the difficulty associated with forecasting localised weather events will result in forecasting errors from time to time. There are also inherent problems with the serviceability of the onsite weather stations and the data networks whereby lack of initial calibration and/or subsequent maintenance have contributed to errors that sometimes remain undetected. The importance of timing has also been explained whereby weather forecasting must be accurate on an hourly basis to reflect the actual heat load.

The potential for error

The preceding discussion identifies many possible sources of error. These have been identified and discussed throughout the course of the study. They highlight the multifactorial nature of the HLI model and its supporting components. They also highlight the need to temper the expectations of the model to better match what can be reasonably delivered. The possible sources of error are as follows:

- Possible false assumptions about the relative weightings of temperature, relative humidity, solar radiation and wind speed within the HLI algorithm (Chapter 5.1.1).
- Possible false assumption in the setting of 25^{o}C BGT as the transitional point between the two formulas (Chapter 5.1.1 and 5.1.4).
- Possible errors due to smoothing (or lack of smoothing) between the two formulas (Conclusions page 62).
- Possible inaccuracies in the calculation of BGT (Chapters 5.1.1 and 5.1.2).
- The disconnect between temperature and relative humidity within the HLI algorithm (Chapter 5.1.3 and 5.1.6)
- Possible false assumptions about the rate of heat load accumulation (Chapter 5.1.5).
- Possible false assumptions about the rate of heat loss (Chapter 5.1.5 and Chapter 5.1.6).
- Possible false assumptions about the existence and/or positioning of the HLI neutral zone (Chapter 5.1.6).
- Inappropriate HLI threshold adjustment in regards to breed type (phenotype, genotype, criteria, linkages and possible exceptions) (Chapter 5.1.8 page 23).
- Inappropriate HLI threshold adjustment in regards to days on feed (body weight, fatness, criteria, linkages and possible exceptions) (Chapter 5.1.8 page 24).
- Inappropriate HLI threshold adjustment in regards to acclimatisation (metabolic rate, coat characteristics, criteria, linkages and possible exceptions) (Chapter 5.1.8 page 25).
- Inappropriate HLI threshold adjustment in regards to coat colour (solar radiation, criteria, linkages and possible exceptions) (Chapter 5.1.8 page 26).
- Inappropriate HLI threshold adjustment in regards to health status (sick and recovering, criteria, linkages and possible exceptions) (Chapter 5.1.8 page 27).
- Inappropriate HLI threshold adjustment in regards to shade (shade-type, shade orientation, criteria, linkages and possible exceptions) (Chapter 5.1.9 page 28).

- Inappropriate HLI threshold adjustment in regards to summer feeding (ration heat increment, DMI, criteria, linkages and possible exceptions) (Chapter 5.1.10 page 29).
- Inappropriate HLI threshold adjustment in regards to water temperature (water availability, fluctuations in demand, time of day, criteria, linkages and possible exceptions) (Chapter 5.1.10 page 30).
- Inappropriate HLI threshold adjustment in regards to manure management (criteria, linkages and possible exceptions) (Chapter 5.1.10 page 31).
- Inappropriate HLI threshold adjustment due to the absence of some other factor (criteria, linkages and possible exceptions) (Chapter 5.1.8 – Chapter 5.1.10).
- Inherent weather forecasting inaccuracies (Chapter 5.2.1).
- Difficulties in forecasting the exact timing of weather events (Chapter 5.2.2).
- Weather forecasting inaccuracies due to lack of bias correction (Chapter 5.2.1).
- Technical glitches with the transfer of information via the HLDN (Chapter 5.2.3).
- Human errors in the transfer of information via the HLDN (Chapter 5.2.3).
- Inaccuracies in the measurement of high levels of relative humidity (Chapter 5.1.3).
- Poor positioning of onsite AWSs (Chapter 5.2.3).
- Lack of initial calibration of onsite AWSs and subsequent drift (Chapter 5.2.3).
- Breakdown or lack of maintenance of onsite AWS equipment (Chapter 5.2.3).
- Localised weather events (Chapter 5.2.2).
- Extreme weather events (Chapter 5.3.5).

This list is not intended to discredit the model. It simply highlights the potential for error in an array of factors within what is necessarily a highly sensitive model. The shortcomings and limitations stemming from this need to be borne in mind to ensure the expectations are realistic.

6.1.2 Inappropriate HLI threshold settings

This report has repeatedly pointed out the importance of accurately attributing adjustments to the threshold factors to allow the model to accurately predict heat load events. This heading is a final reminder. The consultation process found that feedlot managers tend to take notice of the factors they think are important and rather dismiss others as having no relevance. Whilst this may work in many instances, it is important to acknowledge that any inconsistencies may be due to the factors that have been dismissed and not to any failing on behalf of the model itself. Consequently, although it is the responsibility of the feedlot manager to accurately attribute adjustment factors, the industry should provide as much information as possible about the factors, how they link to the model and what possible exceptions might occur.

6.1.3 Excessive reliance on the forecasting service

The way in which feedlot managers may have become more reliant on the forecasting service has also been explained repeatedly throughout the document. It is important that the limitations of the model are properly understood and it is suggested that the end users take full advantage of the management tools inherent in the CHLT.

7 Conclusions

Before drawing any conclusions and/or making any definitive recommendations, it should be recognised that the Australian feedlot industry is a world leader in the way in which it addresses and manages heat stress. No other country takes such a comprehensive, considered, industry-level approach. There is a contradiction, however, as on the one hand the industry possesses a world class, sophisticated model, elegantly simple in its approach, that provides an outstanding framework from which to address heat stress, but on the other hand, the model struggles at times, for the reasons explained throughout this review, to accurately predict a heat stress event. What is also clear, is that although some of the limitations and shortcomings of the model may be overcome by further research, many will not, and the potential for error will remain. Furthermore, the propensity for the model to amplify or accumulate error is also likely to remain, since any attempts to dampen this error will affect the model's ability to correctly predict heat load. Note that heat load can accumulate very quickly under certain circumstances and this is largely what the model is designed to calculate.

Bearing the above in mind, the overwhelming conclusion (drawn by the reviewers) is that the forecasting service has become over-extended. It would appear that in recent times, the focus has moved from a service that provided tools to assist feedlot managers to address and manage the risk of heat stress into a service that is expected to precisely predict heat load events. This has led to a number of consequences. Firstly, it has led, in some cases, to an over-reliance on the forecasting service without a full understanding of its limitations and shortcomings. Secondly, as the inputs into the model become more detailed, there are raised expectations in regards to its accuracy. Thirdly, as feedlots increasingly utilise their own weather stations and as forecast alerts become more sophisticated, inconsistencies have become more evident. In some cases, this has led to a loss of confidence in the service. And finally, this loss of confidence has led the industry to question some of the basic tools that have served the industry so well in the past.

Another finding of the review was an inconsistency in the use of terminology and, to some extent, some inconsistency in the extension material associated with the heat load management. For example, the assumed rate of heat loss depicted in Table 3 of 'Recognising excessive heat load in feedlot cattle' (Tips and Tools) is different to the rate depicted in Figure 5 of the 'Managing Summer Heat Workbook' and the rate used in the current heat load model. This may only be a problem if a feedlot chooses to undertake its own heat load calculations, but it is an area that could be improved.

The reason for the inconsistency in terminology may relate to the purpose of the extension material. For example, material prepared to support industry workshops (Managing Summer Heat) may have a different focus to the general extension material (Tips and Tools). Nevertheless, there is an obligation to maintain a consistent message. An example of an inconsistency is where the TNZ and HLI neutral zone are confused in conversation. Another example is where one of the alerts is termed a rapid HLI change alert, inferring that it is the rapid change of HLI that is detrimental. The alert actually relates to an intensity event that might not be factored or predicted by load due to the rapid change. Note that a rapid change at very low HLI will not cause a problem so the term rapid change is probably not entirely correct. A further example is in the way that the Risk Assessment Program (RAP) and the

HLI threshold calculator are sometimes referred to interchangeably. The RAP is a tool that utilises the HLI calculator to determine the required adjustments and then compares this to historic weather information. The HLI threshold calculator determines the HLI threshold for a particular group of cattle. The RAP assesses the actual risk whereas the HLI threshold calculator does not. It is important that terminology conveys the correct message.

Note that problems with the consistency of terminology within the field of heat stress are not peculiar to the Australian feedlot industry. It is a recognised phenomenon in other areas of thermoregulation study, including the field of human heat stress. In recognition of this, the IUPS Thermal Commission has produced a glossary of terminology that assists in the standardisation of terminology (IUPS Thermal Commission 2003), but even with this, different approaches may often result in different interpretations.

Apart from the above, the most glaring finding of the review is the need for feedback and validation. Currently, the forecasting service providers are in the unenviable position of being vaguely told that the service is not working but then denied the opportunity to properly investigate the incident to determine exactly what has happened. Where investigations have been possible, the explanation has often been relatively easy to determine, and often due to glitches associated with human error or human interpretation (Katestone pers. comm.). This was also the experience of the reviewers. There is a glaring need to develop an immediate feedback loop to enable these investigations to be made. Apart from investigating instances where the forecast has not worked, feedback is also required to help validate the assumptions of the model.

Although the initial assumptions of the model were determined by scientific method, there have been several adjustments to the initial model in response to industry feedback. These include an adjustment to the assumed rate of heat loss (a 'smoothing' between the two formulas as the BGT makes the transition from below 25^{o}C BGT to equal to or greater than 25^{o}C BGT), the rapid change in HLI alert and minor, but significant changes to the HLI threshold factors (the introduction and removal of stocking density as a factor, changes to the way in which acclimatisation has been managed, changes to the criteria relating to manure management). These changes have been made in keeping with the best available science on the subject, but they have not necessarily been determined scientifically. It was also difficult to identify any documentation of the process by which these changes were made. These changes would benefit from scientific validation. Note that there have been several scientific studies since that support aspects of the model (Mader and Davis 2004; Gaughan *et al.* 2010), but it was always assumed that the initial assumptions of the model would be refined by industry validation and feedback (Gaughan pers. comm.). The work required is, however, challenging, and the knowledge gaps involved point to the difficulties involved when dealing with such a multi-factorial model.

The reviewers note the subtle distinction between feedback and validation. Feedback essentially identifies inconsistencies and provides some guidance as to where to concentrate efforts to continuously improve. Validation is a process whereby data generated by the industry is used to scientifically confirm or refine the model assumptions. Validation is more demanding and requires a greater discipline to ensure that all the factors are considered. It also requires large numbers to achieve the necessary statistical levels of confidence.

There are, therefore, many possible sources of information. One is the general feedback that allows specific incidents to be investigated. The second is a more complete set of information that provides general direction and useful clues about the factors involved (this is the sort of information that would generally be collected by feedlots under normal operations). A further tier of information could be generated in the context of an overall experiment. It would collect information in a way that might not ordinarily be collected. This is more demanding and may require additional resources to ensure that the information remains scientifically robust. Another tier of information is the metadata that has been collected over a long period of time and this information resides in the databases of the model. A final tier of information might be the information generated from fully controlled experiments utilising heat rooms. These options are explored in the next section under the heading of Recommendations.

The reviewers note the importance of having the HLI threshold factors set correctly, and this has been discussed earlier in the report. The extent to which errors can be amplified by the model has also been explained. Based on this, it is concluded that the HLI threshold factors should be re-worked based on the most current knowledge and that this be properly extended to industry. Again, this is discussed in more detail under the heading of Recommendations.

Acclimatisation is a special case, since, although it was formally evaluated in the initial scientific work, it has only recently been re-instated as a factor in its own right. It is an important factor and it is the view of the reviewers that acclimatisation may explain many of the inconsistencies within the model. It warrants further investigation. A brief look into the literature shows a strong body of work that documents the influence of acclimatisation on heat production and the animal’s ability to shed heat.

The reviewers also recognise the very good work that has addressed summer nutritional strategies but suggest that it would benefit from a slightly more commercial focus that factors both lowered dry matter intake and performance. No doubt this is done ‘in-house’ in many feedlot operations and the level of expertise in regard to this is very high. It would be of benefit to the industry to see this discussed more openly in the industry extension material.

Without conducting an expansive literature review, it was also clear that, as with many fields of study, there is an abundance of new information about heat stress. In the digital age, science is disseminated and circulated at a much faster rate than ever before. Subsequently there is a plethora of new information, much of which has direct relevance. It was outside the scope of this project to conduct a broad literature review, but it would be in the interests of the industry to conduct a wider literature review that provides new insight into aspects of the heat load model and/or the heat load forecasting service. It is the opinion of the reviewers that this should be undertaken with a view to strengthening the existing model rather than replacing it; and an approach that looks at the overall energy balance would seem to show the most promise.

There are several pivotal scientific papers that provide a solid starting point for this discussion. The most relevant of these is a paper by Thompson that discusses thermal balance (Thompson *et al.* 2014). The author quantifies the heat and water vapour transfer in each of the heat loss compartments (evaporation from the skin, convective heat loss from the skin, evaporation via the respiratory tract, and convection via the respiratory tract). It also compares *Bos indicus to Bos taurus* to highlight the principles involved. The author has determined formulas that reflect the rate of heat loss at all the animal's boundary layers. Another pivotal paper quantifies the importance of body surface area in calculating the possible rate of heat loss for the body surface (Berman 2003). A paper by Rodrigues quantifies the enthalpy relationship and discusses ways in which enthalpy can be measured. There is also work relating to humans that examines metabolic rate and thermal work limits (Brake and Bates 2002). This work is important, particularly if it is possible to connect the findings to assumptions within the model through the use of common units (MJ or Watts).

Weather forecasting plays a pivotal role within the heat load forecasting service. It is, however, a basic service that provides the industry with an 'entry level' forecasting service. The current forecast (KWRF), draws its information from a single model, works to a relatively modest resolution and does not include any bias correction. The BOM's free weather forecast service (ADFD), in comparison, draws its information from a number of models, has a much finer resolution and incorporates bias correction. It also applies a quality control to the forecast whereby the forecast is overseen by the Bureau's operational meteorologists. For these reasons there are some differences in performance between the two models.

The big advantage of the KWRF is that it provides information on solar radiation. The BOM currently does not provide solar radiation as part of the model, and for this reason, ADFD is not a free and flexible forecast that can be readily used for the heat load forecast. Running a weather forecast service specifically for heat load forecast in comparison has the advantage to output a large number of weather parameters.

The performance of the KWRF is reviewed annually. This has provided a great deal of statistical data comparing actual to forecast weather, the KWRF to other forecasts and other comparisons. Whilst these comparisons are valuable, the reviewers consider that the way in which the information is presented could be improved, to make the information more relevant to the industry.

The challenges involved in incorporating information from the on-site AWSs has been discussed. Many possible points of failure have been identified, both in the measurement of the weather elements, and in the transfer of information. Without a vigorous quality assurance program in place, the integration of data into the heat load forecast would seem problematic. The onus, however, is on the owner of the AWS to site, install, calibrate and maintain the AWS equipment and maintain its connectivity (via the HLDN) to a standard that minimises error. The danger is that without a superimposed quality assurance program, these errors remain undetected and become imbedded into the forecasting service. The propensity of the heat load model to amplify small errors has been explained. Guidelines on the installation and maintenance of automated weather systems exist (Bureau of Meteorology 1997; World Meteorological Organization 2008). A co-ordinated approach, which involves all the equipment suppliers, would be required.

8 Recommendations

The following recommendations address the deficiencies identified during the course of the review. However, before listing the recommendations, it is important to give some considerations to the context in which they are presented. It is suggested that the recommendations be part of a 3 year strategy with a clear vision of where the industry would like to be by that time. It is important that the recommendations are enacted in keeping with an overall approach and that they add to, or complement, a consistent purpose.

As mentioned previously, there is no ‘silver bullet’. There are no glaring deficiencies that, once rectified, will allow the service to accurately predict heat load under all circumstances. However, the reviewers have noted shortcomings and limitations in nearly all the facets of the model, all of which have the capacity to compromise the accuracy of the forecast. It is therefore recommended that the industry endeavour to make improvements on all fronts at the same time. Small improvements in all areas will make a big difference to the overall performance of the service and bring it closer to the point where more targeted adjustments can be made with a higher level of confidence.

If funding is limited, it may be that the recommendations need to be carried out in some sort of sequence, whereby progress on one front may depend on work being completed on a different front. This may require a level of finesse, and considerably more co-ordination, but there is a very real risk that work done in isolation will consume considerable resources and deliver very little. For example, although the service begs a system that provides feedback and validation, there is little point in implementing a feedback mechanism that refines the weightings of the threshold factors unless the industry possesses a strong understanding of the biology involved with each of the factors. The industry must be entirely confident that the criteria being used (and the linkages to the criteria) are both scientific and appropriate. It is therefore suggested that any regression analysis based on industry feedback be delayed until after the industry extension material relating to the threshold adjustment factors is reviewed and updated.

Similarly, there is little point in undertaking serious work in experimental heat rooms without knowing which areas of the model appear to be falling down. Some level of industry feedback is required to provide guidance in this area. Furthermore, the industry will find it difficult to accurately identify areas of weakness whilst there is a lack of confidence in the data being generated and utilized by the AWS. Equally, there is little point in undertaking work in the experimental situation without having reviewed current literature to see if there is an alternative approach that can improve the understanding and/or add value to the model.

The final packaging of the research will depend on funding and different levels of funding may affect the priorities. It should be noted however, that the forecasting service is integrally involved in the commercial decision making surrounding heat load and whereas the industry currently accepts the model as a work in progress, there is an obligation to substantially improve the service, and for this to be achieved in a reasonable time frame. There may be a sunset clause involved. The recommendations therefore factor time, priority and approach.

8.1 Overall approach

As previously stated, there is a case to use the forecasting service differently by making better use of the tools within the service at the same time placing less emphasis on a definitive prediction of a heat stress event. The first task would therefore be an immediate communication of this approach. This should be accompanied by strict editing to endure terminology is consistent and as agreed.

8.2 Immediate adjustments

In keeping with the overall strategy, there are some initiatives that could be implemented immediately, and others that could be considered short to medium term. This section addresses the immediate considerations as follows:

- There is good evidence to suggest that the Argonne method of calculating BGT is better than the one used currently (as described in the 2016 progress report) (Katestone Environmental Pty Ltd 2016a). It is more complicated but would appear to be more accurate at higher readings. It is suggested that it can be quickly and easily evaluated and used immediately within the forecasting service if it stands up to scrutiny. Other alternative BGT calculation methods can be reviewed if the complexity of Argonne method makes it difficult to be implemented within the weather forecast data.
- It is suggested that the reference animal used in the model should specify bodyweight (the reviewers assume this to be a bodyweight of 400kg).
- It is suggested that the industry develop a ‘due process’ to formally document any changes to the model and/or the supporting extension material.
- There are several descriptions within the HLI threshold calculation tables that should be changed to better describe the criteria being used (e.g. water temperature instead of water availability, coat colour instead of coat characteristics).
- The KWRF weather forecast should be explored to see if biases (particularly in temperature and relative humidity) can be corrected. This will require BOM’s cooperation to provide real time AWS data to Katestone.
- The terms of reference for the seasonal forecasting reviews should be revisited to provide information in a form that is more easily understood by industry. The review would also benefit from engaging a third party meteorologist to discuss the findings of the review in a forum with the service providers and the industry program/project managers.
- The historic weather data used to assess risk in the pre-summer RAP should be updated.
- Establish an effective feedback loop that allows the immediate investigation of inconsistencies identified by industry.

It is not recommended that there be any immediate changes to the web site and/or industry interface. There is, however, a general consensus that the existing website is too busy and a more simplified site would be more appropriate. There is support for a ‘single line’ approach to depict heat load and it has also been suggested that a ‘scrolling mechanism’ that allows the user to scroll through a number of HLI thresholds (in a similar way to setting an alarm on an iPhone). Another suggestion is that the HLI threshold calculator be devoted a page to itself in recognition of its importance. These changes are consistent with the overall approach outlined above.

Whilst no immediate changes to the website are recommended, it is never too early to initiate discussion about possible improvements. It is suggested, however that action to amend the website be delayed until a later point in the 3 year strategy. It may be initiated to coincide with changes to website hosting arrangements.

In considering the website design, it is suggested that the simple interface be supported by further pages that allow the user to delve deeper if required. This principle would be designed to allow an end user to evaluate an alert to determine exactly what is involved.

The website design might also consider the concept of a tailored service that has a base model with add-ons and/or feedlot specific services that are tailored to the specific requirements of a feedlot.

The industry acknowledges the issues surrounding the use of AWSs. The industry is somewhat divided on what to do with the on-site AWS. There is a school of thought that suggests that the AWS should be removed and another that suggests it should be retained. The reviewers recommend that the current AWS integration be retained, but only if a rigorous quality assurance program can be developed. A co-ordinated approach is required that involves, not only Katestone staff, feedlot staff but also the equipment sellers and/or any other information hubs involved in the HLDN. If a rigorous quality assurance program cannot be developed quickly, two sets of heat load forecasts could be produced simultaneously, one with AWS integration and one without.

8.3 Further research and/or development

The recommendations for future research are as follows:

8.3.1 Improvements to the model

Whilst improvements to the heat load model are likely to be ongoing, there are three areas of investigation that directly address the deficiencies identified within the model.

Heat gain/heat loss

The section on 'explaining inconsistencies' highlights a number of assumptions that could be brought into question. Nearly all of these revolve around the way in which heat is lost or gained from the animal. As stated before, the calibration of the model at the high end of the HLI can be achieved by monitoring the animal. Determining the dissipation of heat load, and what happens at lower HLI levels is more challenging since the changes are largely invisible. Changes to core body temperature are the most reliable clue, but these changes need to be linked to AHLU to allow the assumptions to be validated. One method may be to utilise the enthalpy equation as measured by the wet bulb rise of air moving through the experimental chambers. The assumption would be that whilst heat loss is able to match the heat produced, enthalpy would be equal to heat production. If heat loss cannot deal with the heat production, heat load will be incurred and the enthalpy will fall below heat production. Another method might be the use of telemetry and sensors embedded within the viscera of animals that link heat load to changes to the core body temperature. Again, experimental design and the detail of the terms of reference is paramount.

Possible areas of research could:

- Individually re-assess all the heat load and heat loss assumptions.
- Assign (or confirm) an energy value to an AHLU unit.

- Investigate the intensity event that is not preceded by load.

Acclimatisation

Acclimatisation is a special case. It is suggested that acclimatisation may explain many of the inconsistencies seen in the industry forecasting. As a threshold factor it was couched together with sick and recovering cattle. It is now addressed as a factor in its own right. There has been very little discussion and/or supporting material issued to support acclimatisation as an adjustment factor. Acclimatisation is important because it may shift the position of the HLI neutral zone and change the assumptions about metabolic heat production.

Possible areas of research could:

- Determine how acclimatisation may affect metabolic heat production in the context of the overall energy balance equation.
- Determine how acclimatisation may affect metabolic heat production and the way in which it affects the assumptions of the HLI model.
- Determine to what extent acclimatisation influences the ability of an animal to lose heat in the context of the overall energy balance equation.
- Summarise information in such a way that it can be included into a HLI threshold factor handbook (See 8.3.2).
- Determine how acclimatisation might shift the HLI neutral zone and/or the upper and lower HLI threshold limits.

Summer feeding

As discussed earlier in the report, there has been a substantial amount of good work undertaken that examines how a ration affects heat production. Industry consultation, however, identified that a more commercial approach that factors both DMI and cost of gain, would pull together all of the earlier work and provide managers with a stronger foundation upon which to make decisions.

Possible areas of research could:

- Determine the heat increment of a range of possible ration components.
- Determine the way in which reduced DMI affects heat production.
- Evaluate a number of possible summer production rations that maintain DMI and production and compare the use of these to a strategy that reverts to a heat stress ration as a heat load incident becomes imminent.
- Assess the extent to which a heat stress ration might maintain DMI but lose production.
- Determine the extent to which the feeding strategies influence the overall energy balance equation in terms of heat production.

8.3.2 Extension material

Extension material should be consistent and address all the key aspects relating to heat load in feedlot cattle. It is suggested that the subject material be delivered as a suite of handbooks that are roughly 20-30 page in length with a consistent presentation. These would build on (and probably replace) the Tips and Tools ‘Heat load in feedlot cattle’ along similar lines to the ’Managing Summer Heat’ workbook.

Some of these handbooks could be an output of the recommended research and included in the terms of reference of other projects.

Possible areas of research could:

- Develop a suite of extension material that could include:

    1. *Approach and overview*
    2. *HLI threshold factors*
    3. *Summer feeding*
    4. *AWS & HLDN*
    5. *Feedback and validation*
    6. *Cattle observation (and the use of a hand held app)*
    7. *‘Managing Summer Heat’ workbook designed for industry workshops*

- Develop an industry ‘Glossary of terms’.

8.3.3 Feedback and validation

Feedback and validation is the most critical part of the overall strategy. It is also the most challenging. In the first instance it must be sufficiently resourced to provide appropriate response when required, but flexible enough to have the same resources gainfully employed whilst waiting for heat load events. It must also have a very clear picture of what it is trying to achieve, and this must be well communicated to the industry to ensure that the collection of information is meaningful. Collecting information for the sake of it will quickly lose the trust and co-operation of the industry.

For this reason, it is suggested that the validation project be conducted over a 3 year period. In the first year, the project would focus mainly on responding to identified inconsistencies but introduce a pilot system on a limited number of feedlots. It would be expected to encounter and resolve a raft of anticipated teething problems. In its second year, the project would expand the feedback and collect a sizeable amount of useful information, but it would not be until the final year that the project would generate sufficient information to allow the industry to refine the assumptions of the model with any real level of confidence. Experimental design would be paramount. It is suggested that this project would eventually focus on validating the threshold factors. However, the terms of reference could include a far more all-encompassing co-ordination role. It is likely that this project will require a team approach that would most likely involve the industry consultants.

Possible areas of research could:

- Develop and design a mechanism for the feedback and evaluation of information routinely collected by feedlots.

- Develop and design a mechanism for the feedback and evaluation of information that is not routinely collected by feedlots.
- Develop an extension booklet/handbook that describes the methods by which industry might be expected to provide information for both feedback and validation.
- Follow up the leads generated by feedback by interrogating metadata where appropriate.

8.3.4 Alternative approaches

It is apparent that there is an ever increasing body of work being generated in the field of heat stress. Much of this has direct application to the cattle feedlot industry (Thompson *et al.* 2014). It is suggested, therefore, that a literature review be carried out to identify the most relevant material.

As part of the overall strategy, this project would provide support to the existing model, by providing a better understanding of its limitations. It may provide links to more sophisticated modelling that better reflects what is actually happening at the animal's boundary layers. It is most likely that this would take an overarching energy balance approach. It is not suggested at this stage, that the project aim to replace the existing model. The project may also subject the current model to some parametric analysis to test it against the findings of the literature review.

Possible areas of research could:

- Build on the project work currently underway (B.FLT.0381 and Katestone Environmental Pty Ltd 2015d).
- Undertake a targeted literature review building on pivotal work that has already been undertaken (Thompson *et al.* 2014).
- Investigate the usefulness of the Wet Bulb Globe Temperature (WGT) and/or Wet Globe Temperature Index (Sparke *et al.* 2001; Budd 2008) .
- Strengthen the project by referring to basic text books such as 'Boundary Layer Climates' (Oke 2002) and 'Principles of Animal Biometeorology' (da Silva and Maia 2013).
- Undertake parametric analysis around the current model (possibly around WB and/or solar radiation variations).

9 Bibliography

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10 Appendix

10.1 Industry consultation

9th May 2016 - Meeting with MLA program and project managers – general discussion

1st June 2016 – Meeting with Katestone – general discussion

2nd June 2016 – Meeting with John Gaughan – general discussion

3rd June 2016 – Industry meeting – general discussion

9th June 2016 – Meeting with Des Rinehart – general discussion

10th June 2016 – Meeting with Katestone – general discussion

15th June 2016 – Meeting with Scott Braund, Mort and Co, Toowomba – general discussion

17th June 2016 – Meeting with Katestone – general discussion

22nd June 2016 – Meeting with James Palfreeman, JBS headquarters – general discussion

24th June 2016 – Meeting with Katestone – general discussion

12th July 2016 – Meeting with Katestone – general discussion

14th July 2016 – Meeting with John Gaughan – general discussion

20th July 2016 – Meeting with Bryce Camm, Wonga Plains – general discussion

5th August 2016 – Meeting with Katestone – general discussion

10th August 2016 – Meeting with Li Fitzmaurice – general discussion

10.2 NFAS Accreditation Standards

ELEMENT LM5 – EXCESSIVE HEAT LOAD
OUTCOME: ***The likelihood of an Excessive Heat Load event is monitored, and prompt and appropriate remedial action is taken when required.***
PERFORMANCE INDICATORS: 1. The feedlot must demonstrate the ability and resources to: a) calculate and monitor the Heat Load Index (HLI) and Accumulated Heat Load Units (AHLU). b) conduct a Risk Assessment Program (RAP) for the various classes of cattle in the feedlot. 2. The feedlot has conducted a Risk Assessment addressing the heat stress risk at the feedlot site. 3. The Risk Assessment has been has been documented and addresses the following criteria: • Site climatic factors for the feedlot location; • Animal Factors including genotype, coat colour, days on feed (DOF) and health status; • Management factors which include the provision of shade, provision of additional water troughs, water temperature, ration type, bedding and manure management practices; 4. Each category of livestock has been considered in the Risk Assessment. 5. The Risk Assessment is being reviewed at least once per annum. 6. Management practices are implemented to offset the excessive heat load risks identified. 7. Appropriate documented procedures for managing the welfare of the animals at the feedlot during periods of excessive heat load risks are completed. 8. An Excessive Heat Load Action Plan has been documented and includes: • name of the Feedlot; • name and contact details of the person responsible at the Feedlot • name and contact details of consulting Veterinarian and nutritionist; • allocation of responsibilities to relevant personnel; • threshold of activation for the EHL Action Plan; • actions to manage the excessive heat load event and the welfare of animals at the time which includes; a) Monitoring of livestock, weather conditions, pen conditions, water and feed; b) Operational practices to be implemented for the management of livestock, pens, feed, water and personnel; and c) Maintaining records of daily activities and actions taken where indicated.