On farm

Cooling water for lot-fed cattle

Project number FLOT.322

Report prepared for MLA by:
E.A. Systems Pty Limited
PO Box W1029
Armidale NSW 2350

Meat & Livestock Australia Limited
ABN: 39 081 678 364
Locked Bag 991
North Sydney NSW 2059

ISBN 1 74036 571 2

April 2004

Feedlot

Executive Summary

Water is the most important element for the survival of cattle. Water plays an important role in many essential body functions, including digestion and regulation of body temperature. Limitations on water intake depress animal performance quicker and more drastically than any other nutrient deficiency (Boyles, no date). Increasing water uptake can improve feed conversion, reduce illness, improve cooling ability and improve body functions. Supplying good quantity and quality water encourages increased water uptake that is fundamental to minimising heat stress and maximising performance.

The ideal ambient air temperature for cattle is 5-25^{o}C (T_{db}). In this temperature range the cattle's natural cooling is by heat transfer from the hide into the atmosphere and from respiratory ventilation. With *Bos taurus* cattle being a species that originated from temperate climates, its temperature regulation system is better suited to maintaining temperature rather than cooling in temperatures above 25^{o}C.

The heat stress threshold temperature for *Bos taurus* cattle is 25^{o}C (Hahn *et al.*, 1997). When the ambient temperatures rise above 25^{o}C, the symptoms of heat stress start to become evident though they may not be visible until significant heat loading occurs. High humidity, low wind speed and/or solar radiation also effect heat stress. In extreme situations where ambient temperatures exceed body temperature this process is reversed and cattle actually directly gaining heat. The effects of heat stress have a significant effect on beef production.

Cattle need to be consistently gaining weight for a feedlot to be profitable. Any factors that reduce or inhibit weight gain need to be addressed and heat stress is one of these factors. When cattle become heat stressed they have a reduced feed consumption, which in turn reduces their performance. The probable reason for this is the inability of the animal to dissipate its body heat to a hot environment and the alternative is to reduce heat production through lowered feed consumption (Lofgreen, 1975).

There has been a lot of research conducted with regard to heat stress in cattle (Flamenbaum *et al.*, 1986, Hicks *et al.*, 1988, Gaughan *et al.*, 2001). The majority of this research has been on the effects of shade, diet modification, microclimate and development of an index for heat stress. There has been little research undertaken in Australia on the effects of drinking water temperature and cooling stock by wetting.

Supplying cool water for drinking has a limited direct cooling effect. Other benefits associated with drinking cooler water have a significant indirect impact in reducing heat stress. This includes; increased water uptake, improvements in feed conversion, reduced illness, improved cooling ability and improved body functions (Lofgreen, 1975). It also maximises the cattle's natural cooling ability through sweating, breathing and decreasing body temperature.

Alleviating heat stress in cattle can be achieved by reducing the heat load (shade) or by dissipating heat from the animal to lower its body temperature (spray cooling). If the incoming solar radiation is 39MJ per day, shade reduces this heat load by 70%, or by 27MJ. It is still possible to have heat stressed cattle with shade. In such a circumstance, spray cooling may become important. Spray cooling dissipates a further 15MJ of energy from the system per application (where ambient air temperature 35^{o}C, water temperature is 25^{o}C and relative humidity is less than 60%).

Evaporative cooling ponds (ECP) have the most potential as a cooling system for providing cool drinking water to feedlot cattle, as it is the most cost-effective and efficient cooling system. There needs to be further basic research to determine operating constraints and possible heat dissipation from the system. The pond system also can act as a balancing storage, with cooling and a reduction in evaporative losses enhanced by shading. Most feedlots would already have a water storage that could be used as an evaporative cooling pond.

While the supply water temperature needs to be lowered in some cases (for example, bore supplies), there are some trough designs and practice measures that could be adopted to help reduce the heating of water caused by reticulation systems heating water.

Recommendations

- While supplying cool water for drinking has a limited direct cooling effect, other benefits associated with drinking cooler water have a significant impact in reducing heat stress.
- Drinking water should be supplied at about 16-18°C and not above 25°C.
- The temperature of the drinking water should be consistent.
- An ample supply of water for each animal with adequate access is required.
- Spray cooling cattle should be considered when ambient air temperatures exceed 35°C and when the relative humidity <60%, (T_w=28°C).
- The water temperature used for of spray cooling should be 25°C or below.
- In the wetting phase of spray cooling, thoroughly wet the cattle's hair layer to the skin.
- Modify trough design and practice measures to reduce heating at troughs.
- Evaporative cooling ponds have the most potential as a water cooling system for providing cool drinking water to feed-lot cattle.

Recommendations for Further Research

- Determine the thermal properties of water storages and their suitability as a cooling system.

Glossary

A_{coat}	=	sample area (m^2)
A_k	=	effective conductivity contact surface (m^2)
C	=	the forced convective rate of heat exchange (BTU/hr)
C	=	specific heat, for water C = 4180 J/°C.kg
K	=	non-conductive heat flow (W)
-k	=	thermal conductivity (W/m.K)
L	=	heat flow path length (m)
m	=	mass of water (kg)
RH	=	relative humidity (%)

T_1 = temperature of body 1 (°C)

T_2 = temperature of body 2 (°C)

$T_{ambient}$ = radiant temperature of the surrounding environment (ambient air temperature °C)

T_a = ambient air temperature (°C)

T_{coat} = surface temperature of the hair coat (°C)

T_s = surface temperature of the cattle (°C)

T_w = wet bulb temperature (°C)

v = wind velocity (kph)

ε_{coat} = emissivity of the hair coat (assumed to be 0.97)

$\varepsilon_{ambient}$ = emissivity of the environment or ambient air (assumed to be 0.97)

σ = Stefan-Boltzman constant (5.70×10^{-12} $W/m^2 \cdot K^4$)

INTRODUCTION

Project background

The feedlot industry has recently undertaken research on the effects of various factors, including ration and shade, on the heat loading of cattle. Other work has been undertaken on defining the microclimate of feedlots through projects MLA FLOT.310, "Measuring Micro-climate Variations in Two Australian Feedlots", and MLA FLOT.317, "Measuring the Micro-climate Variations of Eastern Australian Feedlots". Part of Project FLOT.317 studied the temperature of water supplied to lot-fed cattle in a range of water troughs and also measured the temperature of inflow water and water supplies. The study found that trough water temperatures were high with temperatures ranging from 20°C to 34°C.

Cattle maintain their body temperature in extreme heat by temperature regulation. This can be from either a reduction in internal heat load (drinking cool water or diet modification) or increased heat dissipation (wetting or cooling the atmosphere).

The energy balance of a steer is directly influenced by surplus energy derived from digestion of ingested feed, adsorption of radiation, convective losses, evaporative cooling and the temperature of ingested water. The amount of energy required to heat water to body temperature varies as a function of the amount of water drunk and the temperature of the water. The feed intake of cattle is dependent on water intake, which is a function of water temperature. The feed intake determines the amount of surplus energy derived from digestion of ingested feed.

The energy reduction achieved by supply cool water to heat stressed animals is comparatively small, but pivotal. It is important that suppling cool water for drinking or spraying cooling the cattle will adsorb excess heat loads. The loss of energy from the animal to the water reduces heat load and thus provides a mechanism for survival in extreme events of discomfort at times of heat stress. The relative loss of energy is related to the temperature of the water and temperature gradient between the animal, the water and the environment.

Objectives

The objectives of the project are to:

- quantify the effects of supplying cool water to stock with respect to energy reduction and modification of appetite and feed intakes;
- identify existing technologies used to either prevent heating, maintain water temperature or cool water either in storage or at the point of delivery for consumption;
- screen these technologies for possible practical application in feedlots for cooling water for supply to water troughs or for spray systems;
- assess the different systems through an economic appraisal and desktop investigation of the technology;
- define the physical factors influencing the possible use of water sprays for cooling of stock with excessive heat loads using the available data obtained from past studies of feedlot microclimates, and
- report to industry on a shortlist of possible cooling systems and their application.

LITERATURE REVIEW

Thermodynamics of livestock

The laws of thermodynamics dictate that energy is passed from a heated mass to a cooler mass. This law governs many of the processes of energy transfer in an animal and between the animal and its environment. In the case of a heated solid, energy will be passed to the cooler air around it by conduction and convection.

Figure 1 below presents a schematic drawing of the energy balance of a lot-fed steer and some of the transfer systems described above. Key components of these energy transfer systems are discussed in the following sections.

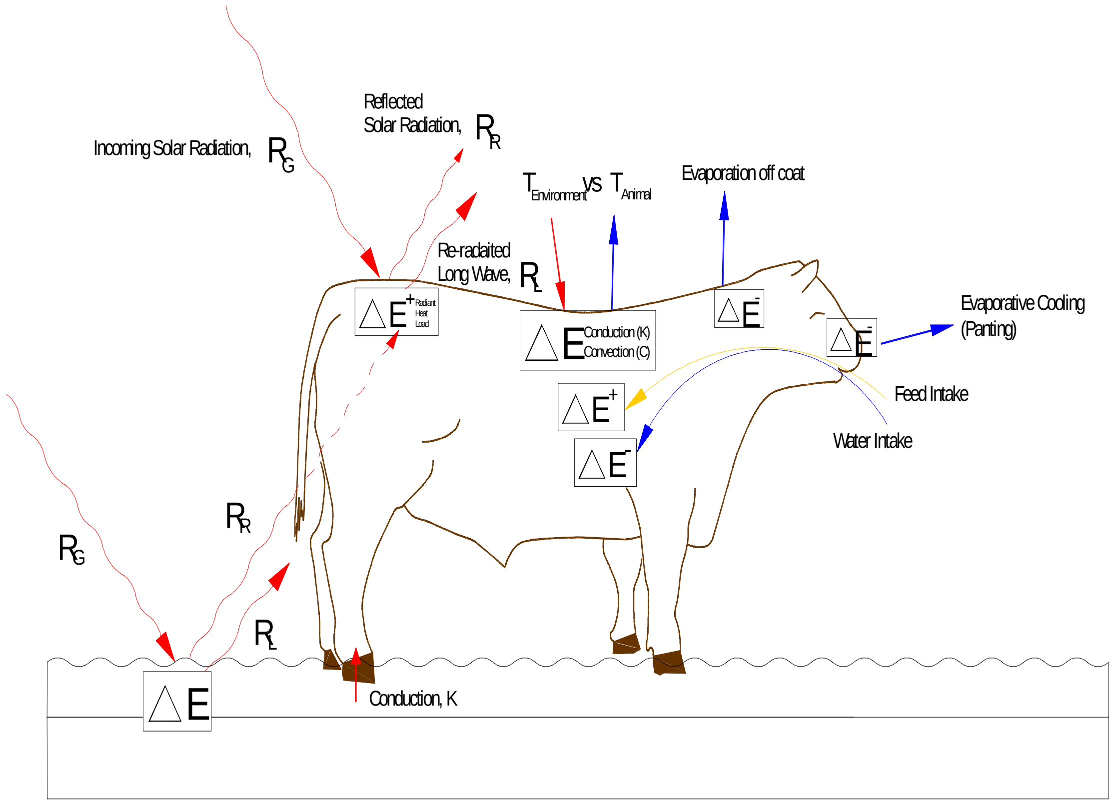


Figure 1. Energy balance of a steer.

Digestion and Metabolic Heat Production

A mass of food is decomposed by microbes in the rumen, resulting in exothermic reactions (that is, heat is released) and some heat is passed from the rumen fluid into the body. A 600-kg steer will consume between 10 to 15 kg of feed per day. On the assumption that 10 kg of feed is consumed, this equates to a consumption of food with a gross energy content of 140 MJ (see page 8 Sparke *et al.*, 2001). Based on these "typical" values of metabolic heat production (MHp), Sparke *et al.* (2001) state that 1,200 W of heat is generated per day (104 MJ). This heat would be transferred from the animal's body to the environment - so long as the air around the body and surfaces in which it is in contact are cooler than its body temperature. These heat losses are by conduction and convection.

Water Consumption

A full grown bullock (~600 kg) will consume about 40 to 70 litres of water on a hot day (water consumption varies as a function of a range of variables including temperature, humidity, cattle size and type, water availability and presentation, and water temperature). If the water consumed is at 15°C, then heat will be transferred from the body of the animal to the water. It takes 4.19 kJ to increase the temperature of 1 kg of water 1°C. Therefore to increase say 60 L of water from 15°C to body temperature (39°C) it requires 6.03 MJ over a day. If the drinking water is "hot" and has a temperature of 25°C, the amount of energy absorbed by the water as it is brought up to the animal's body temperature is 3.5 MJ. While this heat sink is relatively small, the potential "cooling" effects of cold water at times of heat stress are likely to be profound. Therefore, it is important that feedlot water trough design and reticulation systems be designed to present cool water to livestock, even under extremely hot conditions.

Radiant Heating

A body will become heated by radiation. In the case of solar radiation, the amount of energy incident on a surface (based on the days preceding the major stress event at Feedlot B on 8 February 2001 as stated by Petrov *et al*., 2001) is around 8,000 W/m^2. On the basis that the average planar area of a 600 kg bullock (that is, area perpendicular to the aspect of the sun) is 1.5 m^2, then the gross potential for heating is 12,000 W over each day of the two days preceding the stress event. Not all of this energy is transferred to the animal – a large amount is reflected. The proportion of energy reflected is determined by the albedo of the surface. A matt black surface may have an albedo of less than 0.1. That is, less than 10% of incoming solar radiation is reflected and 90% would be absorbed by the hair covering the hide. However, this hair acts as an insulative barrier over the animal that ensures that not the entire 10,800 W of energy (based on an albedo of 0.1) is passed to the animal. This transfer of energy occurs by conduction.

Evaporative Losses

In the situation where the air of the surrounding environment is warmer than the core body temperature of an animal, then the animal must undergo one of two changes. Either it must allow heat storage in the body (an increase in core body temperature); or it must utilise water to sustain evaporative cooling (Oke, 1987). The process of evaporative cooling becomes more important as temperatures increase. This is due to the fact that, as the environmental temperatures rise closer to the core body temperature of an animal, non-evaporative heat losses are reduced due to the smaller temperature gradient between the animal and the environment. In fact, as detailed by Oke (1987), at very high temperatures (in excess of an animal's body temperature) evaporative cooling is the only means of heat loss. Notwithstanding this, the loss of energy by natural mechanisms of evaporative cooling (panting and sweating) is relatively small compared to the overall energy balance.

As cattle have a limited ability to sweat, the main process of evaporative cooling is through their respiratory system (by panting). The main sites of cooling in cattle are in the nasal sinuses, mouth and lungs. The evaporative cooling process involves an increase in the respiratory rate, which is easily identifiable in cattle through rapid, shallow breathing.

Having an inadequate water supply, or a water supply of high temperatures that will increase the heat load on cattle, will break down the evaporative cooling process. Likewise, if the humidity levels of the surrounding environment are high, then there is insufficient humidity gradient between the animal and the air to enable effective evaporative cooling. The use of sprinklers under hot conditions can increase humidity levels and, as a result, may further limit the cattle's ability to dissipate energy by means of evaporative cooling (see Section 0).

Conduction Heat/Energy Transfer

The transfer of the energy in heated hair/hide to the animal body occurs by conduction (or heat from the body to the hair at times when the body is hotter than the hair). The rate of conduction between the air and the body (the theorem for heat conduction) has been described by Sparke *et al.* (2001). It is provided below:

$$K = -kA_k(T_1 - T_2)/L$$ **Equation 1**

where

K	=	non conductive heat flow (W)
-k	=	thermal conductivity (W/m.K)
Ak	=	effective conductivity contact surface (m^2)
T1	=	temperature of body 1 (°C)
T2	=	temperature of body 2 (°C)
L	=	heat flow path length (m)

It is affected by:

- the 'conductivity' of the hair (k); and,
- the effective thermal conductivity contact surface (A_k) which is equivalent to the total surface area of the hide (4 to 5 m^2) plus the additive surface area of the hair. This is assumed to increase the effective surface area to 50 m^2.

Conductivity of the hair is likely to be low and, while radiant load on the hair/hide is high (~12,000 W/day or 1040 MJ), it is most likely that only a small proportion of this energy is transferred to the animal. Few data are available for conductivity values (k). However, tabulated data are provided by Joel (1971) and Young (1992) for various materials. These are summarised below in Table 1.

Table 1. Conductivity values (k) for various materials

Material	k (W/m·K)
Steel	45.0
Glass	1.04
Brick (red)	0.6
Wood	0.12-0.4
Wallboard/paper	0.04
Felt	0.04
Ground	0.04
Air	0.024
Hydrogen	0.14

Oxygen	0.023

Cattle have hair in order to trap air in a layer around their body. The primary purpose of this is to create an air blanket in cold, windy conditions. In this case, the animal is using the air blanket as an insulative protection mechanism and it underpins why hair has low heat conductive properties (that is, to minimise heat loss into this layer). However, by default, the air mass increases the contact surface area of the animal with the greater air mass. Once the hair becomes matted, the effective area is reduced and conduction between the animal and air mass may, in fact, be reduced (contrary to that stated by Sparke *et al.*, 2001). These phenomena are geared to allowing animals to survive in environments where the ambient air temperatures are significantly lower than their body temperature. In these conditions the animal must conserve heat/energy. In warm climates, these basic insulative/thermal characteristics limit the ability of an animal to dissipate heat by conduction and convection.

If the k value for felt is used with an estimated effective area of 50 m^2 (combined hide and hair surface area) and a heat flow path of 12 mm is assumed then the conductive heat flow K can be calculated using the Equation 1 above.

Substituting the above values gives; K = 0.04 W/m·K × 10 m2 × (T1-T2)/0.012 m (Equation 1(b)), so for a 1 K (or 1°C) temperature rise, the transfer of heat is about 33.3 W. If the hide is heated to an average of 50°C for six hours per day, then the energy transfer would be in the order of 80 MJ over the day. This is less than the amount of heat actually generated by the animal (1,200 W) over the day which equates to 104 MJ. Clearly the use of shade will reduce this radiant energy load and thus additional heat load on the animal.

Radiant Heat Loss

As described by Hillman and Gebremedhin (1997), radiant heat transfer (that is, re-emitted radiation, R_L) is determined by knowing the surface temperature of the hair coat and the ambient temperature. The formula to calculate radiant heat transfer is given as follows:

$$R_L = \sigma \times \varepsilon_{coat} \times \varepsilon_{ambient} \times A_{coat} \times (T_{coat}^4 - T_{ambient}^4) \qquad \textbf{Equation 2}$$

where

σ = Stefan-Boltzman constant (5.70 × 10-12 W/m2·K4)

εcoat = emissivity of the hair coat (assumed to be 0.97)

εambient = emissivity of the environment or ambient air (assumed to be 0.97)

Acoat = sample area (m2)

Tcoat = surface temperature of the hair coat (°C)

Tambient = radiant temperature of the surrounding environment (ambient air temperature °C)

Using this formula, values of radiant heat transfer from an animal to the environment under various conditions can be calculated. The value for coat temperature used in the calculations is very conservative and is based on the assumption that the coat temperature is the same as the animal's core body temperature. Realistically this is not the case and there would be a significant gradient of decreasing temperatures as you move away from the centre of the animal. It is likely that coat temperatures could vary as much as 10 to 15°C from the animal's core body temperature on cooler days and may, in fact, be warmer than 39°C on hot days with high solar radiation.

Table 2. Potential radiant heat energy loss from an animal (at 39°C)

Air Temperature		Coat Temperature		Energy Loss	
(°C)	(K)	(°C)	(K)	(W)	(MJ/day)
10	283	39	312	1633.5	141
20	293	39	312	1123.5	97
30	303	39	312	558.6	48
35	308	39	312	254.3	22
40	313	39	312	-65.1	-6

The above table shows that radiant heat loss depends on the temperature gradient between the animal and the surrounding environment. Whilst the animal's temperature remains higher than that of the environment, it is able to radiate heat. As the temperature of the environment rises closer to that of the animals (the temperature gradient is reduced), the amount of radiant energy able to be emitted by the animal is decreased.

Convective Heat Transfer

The effects of convective energy transfer are understated in the "Heat Load in Feedlot" report (Sparke *et al.*, 2001). Overall, the rates of convective heat transfer depend upon the surface temperature and area of the animal, properties of the hair coat, air temperature and its heat holding capacity, and the movement of air over the animal's surface (Esmay, 1969). The movement of air is critical for convective heat transfer as is its heat holding capacity.

The heat holding capacity of air is directly influenced by its moisture content which is described by relative humidity. A clue to the potential adsorptive properties of water is found in Table 3 below which presents data on conductivity of various materials. It shows that hydrogen (which forms part of the water molecule) is a much better conductor than oxygen.

Through laboratory analyses, Thompson et al. (1954) found that the effect of wind velocity (0.18 to 4.47 ms-1) on the rate of total body heat loss of cattle was directly dependent upon the wind velocity and the (gradient) difference between air temperatures and the surface temperature of the animal. At air temperatures near the body surface temperature of the animals, wind velocity had virtually no effect on convective heat transfer. The empirical equation developed by Thompson et al. (1954) was:

Forced Convection Heat Transfer (C) = 4197 – 1.413T_a + 19.35v × (T_s – T_a) **Equation 3**

where

C = the forced convective rate of heat exchange (BTU/hr)

T_a = ambient air temperature (°F)

T_s = surface temperature of the cattle (°F)

v = wind velocity (mph)

This equation shows that the direction of the convective heat transfer between animals and their environment can be out of, or into, the animal depending upon whether the air temperature is below or above the surface temperature of the animal (Esmay, 1969). Table 3 below shows the potential loss of energy from an animal for a range of conditions. The calculation used assumed the body temperature of the animal is 39°C (102°F).

Table 3. Potential Heat energy loss (through convection) from an animal (at 39°C)

Air Temperature		Wind Velocity		Energy Loss	
(°C)	(°F)	(km/h)	(mph)	(BTU/hr)	(MJ/day)
10	50	0	0.00	4126	104
10	50	5	3.11	9177	232
10	50	10	6.22	14227	360
20	68	0	0.00	4101	104
20	68	5	3.11	7410	188
20	68	10	6.22	10719	271
30	86	0	0.00	4075	103
30	86	5	3.11	5643	143
30	86	10	6.22	7210	183
35	95	0	0.00	4063	103
35	95	5	3.11	4759	121
35	95	10	6.22	5456	138

The above data highlight that forced convective heat transfer is highly dependent on wind speed (as stated by Thompson *et al.*, 1954). As can be seen from the above table, there is basically no difference between the potential heat energy losses at 10°C and 35°C when there is no wind. By comparison, with a wind speed of 10 km/h, the potential heat energy loss at 10°C is over 2½ times greater than that at 35°C.

Convective heat loss is also limited by higher humidity levels. Although the relationship between convective loss and humidity is not well defined, it is known that a more viscous air or liquid medium slows convection. As such, air that contains higher moisture levels has a higher viscosity and results in a reduction of heat loss by convection.

Psychrometry and Heat Stress

Psychrometry and the principles associated with it may provide a strong relationship between climatic conditions and the likelihood of cattle heat stress events. As suggested, psychrometry provides an indication of climatic conditions dependent upon both ambient temperatures and humidity. It is useful to sub out critical components of psychrometry. These are provided below.

Psychrometry

Psychrometry is based on wet and dry bulb temperatures and their use to determine humidity (Oke 1978). The differences in the measured wet and dry bulb temperatures provide the relationship that determines the value for humidity. The methods used by psychrometry to determine humidity involve the use of thermodynamic methods for measuring temperature (Oke 1978). Psychrometric charts include wet and dry bulb temperatures, relative humidity, dew point temperature, enthalpy and water content of the air.

Ambient Air Temperature

Ambient air temperature (T_a) is the temperature of the surrounding environment (Oke, 1978), measured with a standard thermometer. This is the standard temperature measurement in most applications. Ambient air temperature is also referred to as the dry bulb temperature (T_{db}).

Wet Bulb Temperature

Wet bulb temperature (T_w) is measured using a standard thermometer covered with a wet wick (Oke, 1978). Due to evaporative cooling from the wet wick, the wet bulb thermometer reads temperatures lower than ambient temperatures (Oke, 1978). By measuring the ambient temperature and the relative humidity, the wet bulb temperature can be calculated using psychrometry methods, or conversely wet bulb and dry bulb temperatures are often used in calculating the relative humidity. The measurement of wet bulb temperature assumes that in the absence of external energy, all the energy used to evaporate the water from the wick is supplied by cooling the air (Oke, 1978) (energy transfer from the air to the water).

Relative Humidity

Relative humidity is the ratio of the mass of water vapour actually present in a unit volume of air to that required to saturate it at the same temperature (Department of Science and Technology & the Bureau of Meteorology, 1975). Oke (1978) also defined humidity as the ratio of the mass of water vapour to the mass of moist air, or quite simply is a measure of the water content of the air. Relative humidity can change with only a change in ambient temperature (T_a), while the water content remains constant and *vice versa*.

Latent Heat Transfer

Latent heat is the heat released or adsorbed per unit mass by a system when changing phase (Oke, 1978). The term 'phase' is used to describe a specific state of matter such as a solid, liquid or gas (Young & Freedman, 1996:9). Latent heat transfer will see no variation in temperature, it is simply a measurement of the energy absorbed or emitted to change phase (Oke. 1978; Young & Freedman. 1996:9). An example of latent heat transfer occurs when water is vapourized through an evaporative process. For this change of state to occur, energy must be added to the system, but if added slowly enough so that the liquid water and water vapour remain in thermal equilibrium, no temperature change will occur (Young & Freedman, 1996:9).

Sensible Heat Transfer

Sensible heat transfer occurs when the addition or subtraction of energy to a body results in a rise or fall in the temperature of that body (Oke, 1978).

Implications of Measuring Psychrometry and Heat Stress

Understanding the heat transfer mechanisms and the evaporation process involved with spray cooling cattle is pivotal to making sense of the potential benefits of spray cooling. When water is applied onto the hide of the cattle there are both sensible and latent heat transfer.

Sensible heat transfer is when heat is directly transferred from the warmer body to the cooler body. Typically with spray cooling, the cattle's hide is warmer than the applied water so heat is transferred from the hide to the water. However, if the hide is cooler, then the heat transfer will be from the water into the hide. This will add to the heat load on the animal contributing to heat stress, rather the alleviating it. Increasing the contact area of the applied water on the animal's hide, increases the rate of sensible heat transfer. So the more thoroughly wet the hide of the animal is, the better the heat transfer (Figure 2). If the applied water contacts only the hair and not the hide, it creates an entrapped air layer between the hide and the applied water. This significantly reduces the heat transfer (Figure 3). Continuous washing of cattle with cool water would provide the greatest heat loss by sensible heat transfer, but is considered impractical.

The latent heat transfer that occurs during spray cooling occurs via evaporative cooling when energy is dissipated from the animal and surrounding air to the water by evaporating the applied water (i.e. a phase change). The rate of evaporative cooling is influenced by water temperature, moisture content of the air and air temperature. The most significant of these is the moisture content of the air. The higher the moisture content of the surrounding air the lower the rate of evaporation and this lowers the rate of potential heat loss from the animal. As the water evaporates, it increases the moisture content of the surrounding air, lowering the rate of evaporation. To counter this, the surrounding air that has increasing water content needs to be removed. This is best achieved by promoting air movement.

Previous studies have attempted to determine climatic conditions leading to potential heat stress events in cattle by measuring wet bulb temperatures only (Barnes *et al.*, 2002). Barnes *et al.* (2002) suggested that wet bulb temperature is a simple measurement that accounts for dry bulb temperature and humidity, and it is considered to provide adequate information while being easy to measure. The measurement of wet bulb temperature with respect to heat stress in animals may be used as an index of degree of comfort as wet bulb temperature combines both the ambient temperature and the relative humidity into a single number. However, with neither ambient temperature nor relative humidity recorded as well, this information can only be used as a relative index and is of limited value when considering the application of cooling methods.

Heat stress is a function of both ambient temperature and relative humidity (Petrov *et al.* 2001), and a rise in one, if not mirrored in the other, is less likely to cause heat stress events. For example, if the ambient temperature is increased while the relative humidity remains constant or is reduced, the likelihood of a heat stress event is less than if both ambient temperature and humidity see a similar rate of increase. Normally heat stress events are due to a combination of increased ambient temperatures and relative humidity.

As heat stress occurs, an animal losses its ability to dissipate heat. This is because many warm blooded animals use latent heat and the change of state from liquid to a gas to remove heat from the body by using it to evaporate water from the tongue (panting) or skin (sweating) (Young & Freedman, 1996:9). If either ambient temperature or relative humidity increases, then the ability of the animal to lose heat through evaporative cooling is lessened as the potential for latent heat transfer is reduced. A rise in humidity will cause this reduction in heat loss as the air becomes increasingly saturated and the potential to transfer water to air is reduced. Therefore the potential for energy transfer and thus for evaporative cooling is reduced. Increases in ambient temperatures reduce the potential for convective heat transfer from the animal due to a decrease in the level of sensible heat loss between the animal and the atmosphere.

Dealing with two factors may become complicated. However, it is the combination of these numbers that determines the significance of the heat stress. For example, an ambient temperature of 33°C does not indicate whether heat stress might be a problem. But if the relative humidity is 10%, heat stress is not likely. Alternatively for that same ambient temperature, if the relative humidity was 95%, heat stress may become an issue.

While the wet bulb temperature is simple to measure, it has limited applications when attempting to determine potential levels of heat stress and possible mitigation strategies (such as spray cooling and misting), and can only be used as a relative index. Thus wet bulb temperatures alone do not provide adequate information to be able to adopt an appropriate management solution that may reduce levels of heat stress.

To determine management strategies effectively, both relative humidity and ambient temperature need to be known so that the appropriate heat loss mechanism can be used. The two heat loss mechanisms that can be determined by relative humidity and ambient temperature are latent and sensible heat transfer. As it is a convective process, latent heat transfer is dependent upon relative humidity whilst sensible heat transfer is dependent on ambient temperature.

Effect of Drinking Water Temperature

There are many factors that influence water uptake by cattle, which include air temperature, humidity, water content of feed, loss of sweat due to excretion and temperature of the water (Petrov, 2002, Harricharan, 1999). Providing water at near the optimum temperature will increase the water uptake of the cattle (Lofgreen, 1975). It also maximises their cooling ability through sweating, breathing and decreasing body temperature (absorbing energy to increase drinking water temperature to body temperature).

The optimum temperature for water to be supplied to cattle varies for different reports. The following reports concluded the following: Lofgreen (1975) concluded that 18°C was the optimum water temperature, whilst Harricharan (no date) recommended 16 to 27°C. The conclusions of Lofgreen (1975) came from an experiment that varied the water temperature and noted the effect on performance. The only water temperatures that were trialled were 18°C and 32°C. Suppling water at the lower temperature improved the performance of the cattle. Harricharan (no date) stated “research has pinpointed the optimum temperature of drinking water at 16 to 27°C”. The research being referred to was not outlined or cited.

Bos taurus cattle in a hot environment consumed more feed, gained more weight and improved energy utilisation when given access to cooled water at 18°C compared to 32°C (Lofgreen, 1975). Tests conducted from 1950 to 1955 in California, showed the daily weight gain to be an average of 0.16 kg/day (Itter *et al.*, 1958). This trend was only noted in *Bos taurus* cattle and not in *Bos indicus* crossbreds. The *Bos indicus* crossbred cattle performed similarly on cold or warm water. Warm water did not affect the *Bos indicus*-cross cattle’s performance, feed intake or energy utilisation. Lofgreen (1975) found supplying water at 18°C was sufficient to absorb excess heat from the extra feed consumed in the given conditions.

Jones (1999) noted cattle preferred a water temperature between 21 and 30°C. This means if both warm and cool water were provided within the same pen, the cattle would drink the warm water. But the literature generally noted that supplying cool water increased the weight gain of the cattle. Combining these findings, the optimum temperature with regard to performance of the cattle and the system would be 16-18°C. Not withstanding this, if the water temperature entering the trough is between 20 to 25°C, then the benefit of cooling might not be significant enough to warrant cooling.

When cattle become heat stressed they have a reduced feed consumption, which in turn reduces their performance. The probable reason for this is the inability of the animal to dissipate its body heat to a hot environment and the alternative is to reduce heat production through lowered feed consumption (Lofgreen, 1975). Providing cool water allows the cattle to cool letting them consume more feed. The amount of extra feed that can be consumed is when the amount of energy required to heat the cool water to body temperature equals the heat produced from the extra feed. An optimum water supply would be able to absorb any excess heat that the cattle produces from the feed consumed.

For every 1°C increase in water temperature, there is an additional 4.18 kJ of energy added into the system. While trying to alleviate heat stress, it is evident that the lower the water temperature, the better. While providing cool water is beneficial, it isn’t always economical. Water needs to be supplied at a temperature that does not contribute to heat stress and is economical. The heat stress threshold temperature for cattle is 25°C (Hahn *et al.*, 1997). When the ambient temperatures rise above 25°C, the symptoms of heat stress start to become evident. This means the maximum water temperature that does not contribute to heat stress is 25°C. If the water temperature entering the trough exceeds 25°C, then it needs cooling or it is likely to contribute to heat stress.

Providing cool water has significant benefits, but it is no substitute for adequate supply. Supplying good quantity and quality water encourages increased water uptake that is fundamental to minimising heat stress and maximising performance. Adequate access to the water supply is also important to ensure all cattle can drink readily.

In summary, there are numerous and substantial benefits for supplying cool water to cattle. It encourages increased water uptake that is fundamental to minimising heat stress and maximising performance. It improves feed conversion, reduces illness, improves cooling ability and improves body functions. It also maximises their cooling ability through sweating, breathing and decreasing body temperature (absorbing energy to increase water temperature to body temperature). The recommended optimum temperature to supply water to cattle is 16 to 18°C.

Spray Cooling Cattle

Methods Cooling Cattle

A method of cooling cattle is by enhancing a direct cooling mechanism; evaporative cooling from the skin (Shearer, 1999). Applying water on hair coat to the skin surface is an effective way of cooling animals. Another way to cool cattle is to lower the ambient air temperature.

With wetting cattle by spray cooling there are two heat transfer mechanisms from the animal, latent and sensible heat transfer. Latent heat transfer occurs in the evaporative cooling process. This heat loss mechanism is achieved when cattle are thoroughly wet and allowed to dry. The heat is dissipated in evaporating the water. Sensible heat transfer occurs when heat is transferred from a warmer body to a cooler body. Clearly the water must be cooler than the animal. This transfer can be between the cattle, water and air.

Hillman *et al.* (2001) noted that evaporative heat loss was the major mode of heat loss of the wetted skin. With very little air movement, wetting their skins alone increases heat loss from 70 to 400 W/m^2. Convection becomes a major mode of heat loss at high airflows over a non-wetted hide. Heat loss by convection at high airflows of over 2.2 m/s on a non-wetted hide is approximately equal to evaporative heat loss with no airflow. While these results were based on good experimental data, it was only for a specific ambient temperature range of 30-35oC and relative humidity of 60%. However, when wetting is combined with airflow the cooling benefit is additional for the given conditions of that experiment.

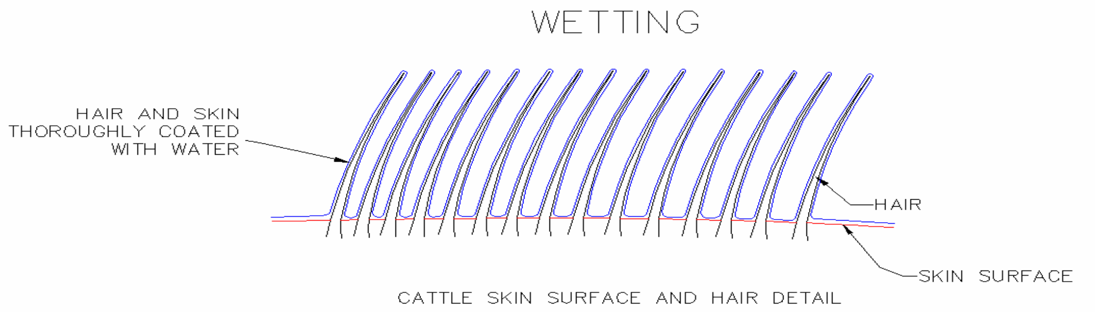
Jones *et al.* (1999) looked at several other cooling methods, including cooling the air. This method generates a mist which absorbs energy from the air, cooling it. This allows increased heat loss from the animal. No literature was found on the use of refrigerative systems.

Factors Influencing Cooling Cattle

Spray cooling water has several effects on the cooling of cattle. The water that is applied absorbs heat from the animal, but the effects are far greater than this alone. Oke (1987) describes the interaction between the atmosphere and animals as one of the highest levels of complexity in a “boundary layer” microclimate. As a consequence, the interactions are not well understood and very little literature is available.

With cattle originating from temperate climates, the hair on the cattle acts as an important insulation barrier to conserve heat. When cattle are moved to warmer climates their hair continues to conserve heat loss, exasperating heat stress. By applying enough water to wet through the hair layer to the skin, it changes the properties of this insulation barrier. Instead of the hair creating a microenvironment to prevent heat loss, the water becomes a mechanism for cooling. While the water temperature is less than the air temperature, heat is conducted from the skin to the water. This heat transfer evaporates the water and cools it allowing more heat to be conducted from the skin. Sensible heat is converted to latent heat at the skin surface.

The extent of cooling attained is dependent upon thorough wetting of the hair layer (Flamenbaum, 1986). This allows good conduction from the skin to the water and it also maximises the amount of water that can be applied. This is best achieved by using low pressure, large droplets which penetrates the hair, wetting through to the skin as shown in Figure 2 below. If high pressure and/or small water droplets are used, it can actually create a layer of water outside the hair layer, trapping a layer of air as shown in Figure 3 below, or by flattening the hair against the skin. This air layer acts as an insulation layer reducing heat transfer between the skin and the water, which reduces the cooling of the animal.



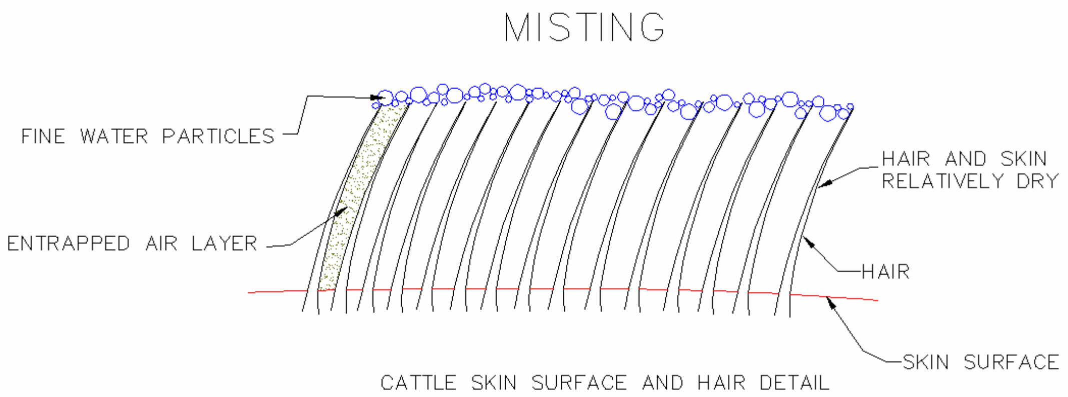


Figure 2. Effects of through wetting.

Figure 3. Effects of mist wetting.

Cattle have natural responses and mechanisms for thermo-regulation. If their climate changes significantly so will their natural responses. If the water that is applied is too cool, the cattle's natural cooling mechanisms will respond to these cool conditions and will reduce cooling to balance to the condition, and in extreme cases they will try and conserve heat. This effect is undesirable and needs to be avoided where possible because the cattle need to maintain a cooling ability.

Relative Humidity

Relative humidity reduces the natural cooling ability of cattle. Brouk *et al*. (2001) found that spray cooling can increase the relative humidity, contributing to heat stress rather than relieving it if a system isn't set-up and managed properly. With this cooling process being dependent on latent heat transfer, the vapour gradient between the skin and the ambient air is the driving mechanism. This makes the humidity of the ambient air important as it effects latent heat transfer.

There has been a reasonable amount of research on spray cooling combined with fans in the humid environments such as the dairy industry in Florida, USA. Flamenbaum (1986) noted that spray cooling can create a moisture-rich environment. It was generally noted that spray cooling in humid areas is most effective when combined with increased wind speed. As humidity increases, increasing wind speed can compensate for the otherwise reduced rate of energy transfer by increasing heat and moisture removal.

Petrov *et al.* (2001) observed that the feedlot environment had increased relative humidity levels over ambient. The use of sprinklers for the purpose of cattle cooling would further increase these levels. Spray cooling adds water into the pen environment, increasing relative humidity. In times of low wind speed (which can occur at times of excessive heat) this local increase in relative humidity becomes significant and will actually cause additional heat loading of livestock by reducing the efficiency of loss mechanisms (sweating etc.).

Effects of Wetting Cattle

It is likely that evaporative cooling could be increased by artificial means through the wetting of cattle. However, while this may have a useful instantaneous effect on stock, it has the potential to exacerbate other stressors in the period after initial wetting and subsequent drying of stock. The detrimental effects that may arise due to the use of sprinklers include:

- increased humidity levels;
- reduction in natural evaporative cooling;
- reduction in energy losses through normal convective processes;
- increased moisture content of pen surfaces and potential increase in ammonia generation.

As such under hot still conditions where the primary means of heat energy loss are already limited (that is, convection, conduction, and radiant heat loss), the increase in humidity levels potentially created through the use of sprinklers can limit heat loss by evaporative cooling and further reduce convective losses. Therefore it possibly contributes to heat stress following the initial wetting of stock.

Current Practices and Technologies to Cool Cattle

Listed below are some current practices and technologies used to spray-cool cattle. Some of these practices are used in other countries with vastly different climates to that of the Australian lot-feeding industry and are used within the dairy industry.

High Pressure Foggers

High pressure foggers disperse a very fine water droplet into the atmosphere, which is quickly evaporated and cools the air. Fans are then used to blow the cool air onto the cattle for cooling. This cooling method increases the relative humidity, which can increase heat stress, ammonia production and odour.

Misters

Misters disperse a fine water droplet, but the droplet is larger than the fog droplet. The droplet again evaporates, cooling the air. The air then cools the cattle. Mist systems are only successfully when used in conjunction with fans or in windy conditions. The mist droplets are too large to be evaporated before reaching the ground. If the mist only wets the outside of the hair and not the hide, an insulating layer of air can be trapped between the hide and the mist on the outside of the hair (Figure 2 and 3 above). This will reduce evaporative cooling from the animal. This cooling method also increases the ambient air's relative humidity, which can increase heat stress, ammonia production and odour.

Sprinkler Systems

Sprinkler systems disperse large water droplets to wet the hair coat to the skin of the hide (see Figure 2 above). Cooling occurs when the body heat is transferred to the evaporating water (evaporative cooling). Convective cooling which increases with air velocity can enhance this process. If more water is applied than what can be captured by the hide and hair, this excess water will run-off the animal onto the ground. This will increase the relative humidity and ammonia production that decreases the ability of the atmosphere to evaporate water. If there are significant amounts of excess water it could have environmental impacts with regard to odour and wastewater generation. To minimise these problems, the sprinklers can be operated intermittently, so the sprinklers operate for long enough to wet to the hide, then shut off till the hide is dry again.

Spraying at Night in Extreme Conditions

It has been found that cattle need a recovery period in times of heat stress. Feedlot deaths are substantially higher when there is no night time relief through lower ambient air temperatures. Spraying at night is associated with lower ambient temperatures and minimal incoming solar radiation. This is thought to be a more effective time to cool the cattle considering the prevailing environmental conditions. There are concerns about the microclimate and environmental impacts. In times when night temperatures stay elevated it is associated with increased moisture in the atmosphere. This would be further increased with night cooling. The effect of cooling is reduced as relative humidity increases. Spraying at a time with minimal solar radiation, often reduced wind and lower ambient temperatures may mean that the pens are going to stay wetter longer, having several negative impacts. Therefore, night cooling should be used with caution and in instances where Ta is high (>22°C) but RH remains low (<65%), the pen surfaces are very dry and air flow exists.

Ground Sprinkling System

Ground sprinkling systems are used to intermittently apply water to the feedlot floor to cool the feed-lot pen surface on which the stock lie, thus allowing cooling by conduction. This system was trialled in an experimental feedlot (Davis, 2001). While this method lowered body temperature the benefits were found to be small.

Fan Cooling

Gaughan *et al.* (2001) found that increasing air speed alone has a significant effect on cooling, while the temperature was below the average body temperature of 38.5°C. As the ambient temperature approached body temperature this cooling effect became significantly reduced. When the ambient temperature increased above body temperature it actually heated the animal rather than cooling it.

Summary

Sprinkler cooling systems are generally considered to be the most economical and practical way to cool cattle (Turner, 1997, Shearer, 1999). The system is significantly enhanced when used in conjunction with fans to increase convective cooling (Jones *et al.*, 1999). There has been a lot of work done in the USA with dairy cattle, as heat stress significantly affects milk production. There is only a limited amount of information found on feedlot applications.

The alternative to these cooling methods are dietary manipulation and providing shade. In times of heat stress reduced feed intake is an effective and natural method of controlling body temperature. The reduced intake lowers the excess heat produced, also lowering the weight gain. Providing shade will reduce the incoming solar radiation heat loading on the cattle. The combination of these measures may be required to combat heat stress in extreme climates.

Commercially Available Technology on Water Cooling

There are several commercially available technology systems to cool water, maintain cool water temperatures, or prevent heating of water. This literature review will investigate the efficacy and practical application of a range of these systems. There are several places within the system where these technologies are used, which include:

Cooling Water at Source

Heat Exchanger

A heat exchanger (Figure 2) uses systems that transfer heat from one substance to another, typically liquid to liquid. Heat exchangers are widely used for commercial and industrial applications when cooling to low temperatures are required, also when cooling significant temperature ranges. Typically, these systems are more expensive, both in capital expenditure, operational costs and on-going maintenance. Feedlot applications would require a large commercially available system, which would be very expensive.

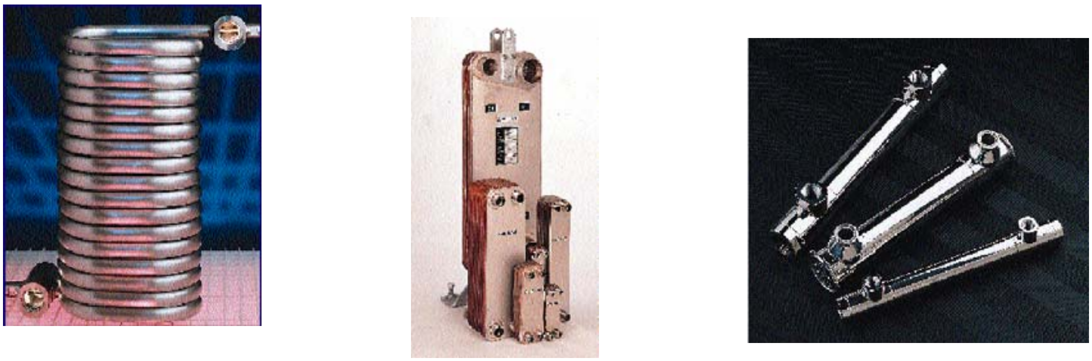


Figure 4. The common types of heat exchangers are coil, plate and shell-and-tube.

Coil Heat Exchangers (see Figure 4) have a long coiled tube of small diameter placed in a larger tube. One fluid passes trough the inner tube and the other trough the outer tube. The heat is transferred between the inner and outer tubes. This is a simple, robust and economical exchanger that can handle a larger temperature range. They have poor thermal performance due to the small heat-transfer area. These exchangers are better suited to low flow situations because of the small diameter singular tube.

Plate Heat Exchangers (see Figure 4) consist of a series of thin plates with two separated flow paths. Each fluid path passes alternative between adjoining plates. The heat is transferred between the plates from fluid to the other. These plates are corrugated to enhance heat transfer, strength and turbulence. They have high heat-transfer coefficients and area. They tend to be very effective, but are limited to low pressure systems.

Shell-and-tube Heat Exchangers (see Figure 4) are a bundle of parallel tubes inside a larger shell. One fluid passes through the tubes, while the other passes between the shell and the tubes. The hot fluid (the fluid being cooled) generally passes through the tubes. Baffles are placed perpendicular to the tubes inside the shell for tube support and separation and to direct flow across the tubes. The performance of this type of exchange is between the coil and plate exchangers.

When cooling water for feedlot applications, the head loss of these systems (friction of water in the reticulation system) can become relative high and needs to be considered, particularly in the case of medium to high flows. Water quality can be a significant issue with these systems. Corrosive waters and solid particles can cause the system to wear quickly increasing costs. While heat exchangers transfer heat efficiently, they require a cooler liquid to transfer the heat to.

In feedlot applications finding enough cool liquid for the system to operate will often be the limiting factor. These systems are more suited to cooling lower flows by a greater temperature using a refrigerated liquid. A large system would be required to cool 15 l/s (1.3 ML/day or approximately 25,000 head @ 50L/day) by 10°C. This system would be most suited to only the smaller feedlots with a very hot bore, requiring a large cooling requirement.

Cooling Tower

A cooling tower (see Figure 5 and Figure 6 below) exchanges heat from warm water to cool dry air. This is achieved by spraying water in a rain-like pattern through the air, so they come in direct contact with each other and allow the transfer of heat. The cooling mechanism is from convective heat transfer of the water or evaporation. The energy that increases air temperature and evaporation comes from the heat loss from the water.

Figure 5. Induced draft cooling tower.

Figure 6. Forced draft cooling tower.

There are several basic designs for cooling towers, but all have a few basic components. These basic components are:

- *Frame and Casing* - The tower needs a frame for support to hold all the components in position. The casing of the tower encloses the components to shelter them from the external environment.

- *Hot Water Inlet* - This is at the top of the tower and usually entails spray nozzles that apply the water to the fill. The hot water falls through the system by gravity.

- *Fill* - Most cooling towers use fill to enhance the water-air interaction to maximise heat transfer. The fill does this by continually breaking the water into smaller droplets. The fill can be constructed from plastic or wood and consists of successive layers of horizontal splash bars.

- *Cold Water Basin* - This catches the cooled water that flows down through the fill and tower. It is located at the base of the tower. From here the water is ready for use.

- *Air Flow/Fans* - Airflow is needed for the system to operate efficiently. Increased airflow increases the performance of the system. There are several air circulation methods used.

- *Induced Draft* - Is where the fans are pulling air through the system, hence being located near the air outlet. Propeller fans are generally used. This can be used in a cross and counter flow system.

- *Forced Draft* - Is where the fans are pushing air through the system, located near the air inlet at the base of the tower. Both centrifugal and propeller fans are used. This system is limited to counter-flow systems.

- *Natural Draft* - Is where the airflow is not mechanically enhanced. It uses temperature gradients and wind for airflow.

- *Air Inlet* - Is where the air enters the system. Louvres are sometimes used to equalise airflow into the fill and to minimise drift from the tower. There are two basic air inlet designs.

- *Counter-flow* - Air enters at the bottom of the tower and exists at the top.

- *Cross-flow* - Air enters from either one or both sides of the tower and exists from the top of the tower.

The extent to which the water can be cooled by the air depends on the environmental conditions. Things that effect cooling tower design and size are the approach, wet bulb temperature, range and heat load. The approach is the difference in temperature between the wet bulb temperature of the inlet air and the cold water or outlet temperature. The wet bulb temperature is the theoretical minimum that the water can be cooled to. The typical approach values are between 3-12°C. As the approach temperature is decreased the cooling tower size increases exponentially. Ambient temperature and relative humidity influence the wet bulb temperature, which affects the approach temperature. The range is the temperature that the water is cooled by. The heat load is the amount of energy that is transferred from the water. The greater the heat loads the greater the cooling tower design.

There are a few issues that need to be considered before adopting this system. These include heat issues, water treatment and weather conditions. The bacteria that cause legionnaires disease can thrive in cooling towers under certain operating conditions. Water quality needs to be continually monitored and treated when required. As a result this system would require to be licensed. Water monitoring and treatment may be needed for other issues like algae control.

The weather conditions effect the performance of this system as it is dependent on the wet bulb temperature of air entering the tower. Ambient temperature and relative humidity influence the wet bulb temperature. Where ambient air temperature and relative humidity is high it will limit the cooling ability of the system.

This system is suited to cooling very large flows (<1400 l/s), a relatively small amount (5-15°C). The approach temperature (the temperature difference between the cold water temperature and the wet bulb temperature of the incoming air) is a limiting factor to how cool the water can be cooled within the tower and is typically about 10-35°C.

This method of cooling is widely used for commercial and industrial cooling purposes. It is also associated with very large cooling requirements. Some applications are in power stations and very large evaporative air conditioners. This system is generally considered to be an effective method of cooling large amounts of water.

The typical of the types and sizes of cooling towers that would be used in these situations can be seen in Figures 5 and 6. These units are prefabricated and transported onsite. These prefabricated units cost approximately $20 000, which does not include site works, connections (electrical and water) or transport from factory. The capacity of a typical unit is:

Water flow rate:	20.0 l/s (1.7 ML/day or approximately 34,500 head @ 50 L/day)
Inlet water temperature:	35.0°C
Outlet water temperature:	27.0°C
Entering air WB temperature:	24.0°C

Evaporative Cooling Pond

A method to cool water is to use a large storage (several days of water supply) and let it cool water through evaporation of surface water (Figure 7). The heat is dissipated through evaporating the water from the storage surface. This would create a temperature gradient in the water profile, with the cool water on the bottom. This would allow further cooling at night, where heat would radiate from the warmer water to the cooler atmosphere. A water supply could then be drawn from the bottom of the pond where it is coolest.

Evaporative cooling ponds could be a very effective, yet cheap method of cooling. It requires minimal capital cost and very low operating and maintenance costs. The management of this system is very low. While this system has enormous potential benefit for the beef industry it needs further basic research to determine operating constraints. Things that need to be determined are: temperature gradient versus depth of storage, influencing factors of temperature gradient, possible heat loss, potential cool water temperature, storage volumes and depths required and possible problems. Other things that could be considered are the options of enhancing this system, by shading or covering the pond.

Water quality issues may arise due to the unlined nature of these storages, allowing dirty water and aquatic vegetation into the system. This system is suited to most applications, handling large flows and high cooling requirements. A typical evaporative cooling pond that would be used in these situations can be seen in Figure 47 below. The construction of the earth storages costs approximately $10, 000 for a 2.5 ML storage.

This method of cooling is widely used in western Queensland for town and stock-water supplies for cooling water from bores drawing hot water from the Great Artesian Basin. A typical cooling grid pipe network that would be used for supplying 1.5 ML/day or 30,000 head @ 50 L/day, in these situations can be seen in Figure 57 below. The earthworks cost approximately $10,000 and the pipe network cost is approximately $15,000.

Figure 7. Evaporative cooling pond.

Cooling Grid (pipe network/radiator immersed in water)

A cooling grid (see Figure 8) uses a water storage, typically a ring tank or dam, as the cooling medium. The water that is being cooled is passed through a pipe network immersed at depth in this water storage. Cooler water at depth is generated by heat being dissipated from the water surface through evaporation. A temperature gradient forms with the cooler water at the bottom, where the pipe network is located. These earth storages are constructed and pipe network assembled inside. The ponds are then are filled with water.

Figure 8. Cooling grid.

The materials used are very important because of the corrosive environment in the pond. The pipe is generally copper due to its inert properties, but galvanised and painted steel pipe have been used. The systems cooling ability is limited by the water temperature of the pond which is influenced by its evaporative cooling ability (see Section C). This system is more suited to low to medium flows with a medium to high cooling requirement. This system has potential if a closed system is required (where the water supply stays enclosed within the pipe network, not coming into direct contact with the dam water). If a closed system were not required the evaporative cooling pond is more likely to be more economical.

The system's cooling ability is limited by the water temperature of the pond. This system is more suited to low to medium flows with a medium to high cooling requirement. This method of cooling is widely used in western Queensland for town and stock water supplies for cooling water from bores drawing hot water from the Great Artesian Basin. This has the benefits of keeping the water clean and with artesian water it maintains the bore pressure, saving on pumping costs.

A typical cooling grid that would be used in these situations can be seen in Figure 4. These earth storages are constructed and then pipe network assembled inside. The earthworks cost approximately $10,000 and the pipe network cost is approximately $15,000.

Cover the Water Source

Shading the water storage will reduce direct heating of the surface waters. The shade needs to be set-up to allow good ventilation between the shade and the water surface to enhance evaporative cooling. This will create a temperature gradient in the storage to form in a similar fashion to the cooling ponds (see Section 2.6.1). The water could then be supplied from the cooler depths. If the water storage were of significant size, the night cooling effect would also help. This water storage could also act as a balancing storage. This system would be able to cool water to about 25 to 30°C. It is a cost-effective open system. Open systems allow algae and silt to enter. This method could be combined with a heat exchanger, cooling pond, cooling tower or large water storage.

Another method is to cover the water surface with a floating material to minimise solar radiation heating the water and to act as an insulative barrier. The will also keep the water storage weed and algae free, due to the reduction in light. The main cooling that a water body has is evaporative cooling, which this insulative barrier would minimise, so if the water were cool, this would help in keeping it cool. This method could be combined with a heat exchanger, cooling pond or cooling tower.

Refrigeration System

Refrigerative coolers operate using a compressor, being driven by electricity or a motor. The environmental operating conditions of refrigerative systems are larger than all the other systems mentioned, as they are not directly affected by the weather conditions. They have the greatest ability to cool a large temperature range (>60°C), but are more suited to lower flows. This system has a high energy requirement (electricity), along with expensive capital and maintenance costs. They also require specialist equipment and technicians to set up and maintain. These systems are very effective, but are not always the most efficient.

This system would require a large commercially available system costing in excess of $50,000. The cost as opposed to the benefit is prohibitive for both capital and maintenance costs.

Pipe Temperature Maintenance

Pipe temperature maintenance is important in suppling cool water efficiently to either the trough or for spray cooling. If a pipeline is on or above the soil surface it gains a huge heat loading from solar radiation and the atmosphere. The heat gained by the water within the delivery system needs to be minimised. Burying pipes, selecting pipe materials and insulation existing pipes can achieve this.

To prevent significant heating from solar radiation and atmosphere it is important to bury all pipes at depth. There is a significant temperature gradient in the soil up to about 600 mm. The soil surface temperature varies significantly and is directly related to atmospheric conditions. As you go deeper into the soil, the effect of atmospheric conditions decreases. Temperature is considered to be fairly consistent at 300 mm on a daily basis and 600 mm on an annual basis. Therefore bury pipes at depths greater than 600 mm.

With burying the pipes, corrosion of certain materials will be of major concern, particularly metals. Materials that are good thermal conductors would allow a significant amount of cooling or heating. When the cooled water temperature is less than the soil temperature and heat is transferred into the water, the soil temperature around the pipe and the water temperature needs to be compared to see if heat is being gained. Practically this could be as simple as placing a mound of dirt over existing exposed mains.

Selection of pipe materials - can reduce the heat gained by the water. Typical materials that are used are polythene, PVC, galvanised steel, black steel and copper. Materials that have insulation properties and are corrosion resistant would be preferential to reduce heat gained. Availability and ease of maintenance will also need to be considered. Polythene pipe has these desired properties, but is limited to water temperatures <50°C.

Coating of existing pipes - to prevent excess heat from entering the system. Increasing the installation properties or lowering the sheer thermal mass of the pipe would help achieve this. This could include painting the exposed pipe white and/or shading/covering the existing pipe network. This might mean an enveloping pipe is used to prevent solar radiation from heating the existing system.

Cooling Water at Consumption Point

The water could be cooled or further cooled as it enters the trough. A mini cooling tower at or into the trough could achieve this. The use of a bubbler could also be considered. No bubblers for trough systems were noted in the literature search, but such a simple cooling system is worth while investigating for feedlot water systems.

Where the pipes to the trough are buried, the heat transfer from the water into the ground could be used to cool the water in situations where the deep in the ground is significantly cooler than the water (for example, southern regions of Australia). It would also require the material of the pipe to be reasonably conductive, which often means it would be prone to corrosion. The system performance would be dependent on the flow rate and pipe diameter.

Summary of Commercially Available Technology for Water Cooling

There is a large range of commercially available technology for water-cooling. These technologies are used over a broad range of industries from power generation to retail. Some of these cooling systems might have a possible used in the feedlot industry, but the mechanical systems are generally very expensive. A summary of the systems is provided below.

Heat Exchangers - While heat exchangers are effective at transferring heat from one fluid to another its application in feedlots is limited. A major limiting factor is this system needs a second fluid other than the one being cooled. This second fluid acts as the heat sink requiring it to be at least 5°C cooler than the cold water temperature. If there were a cold water source it would be used rather than be used to cool the second cooling fluid. These systems are more suited to where the cooling fluid requires being in an enclosed system. Feedlot applications would require a large commercially available system, which would be overly expensive.

Refrigerative System - The cost versus the benefit would be prohibitive for both capital and maintenance costs. This system would require a large commercially available system and incur massive operating costs.

Evaporative Cooling Pond - This cooling system has the most potential, as it is the most cost-effective and efficient cooling method. There needs to be further research to quantify the benefits, temperatures and possible heat dissipation mechanism and optimisation. This system also can act as a balancing storage and can be enhanced by shading. Most feedlots would already have a water storage that could be used as an evaporative cooling pond. The cooling mechanisms are natural and do not require additional inputs.

Cooling Pond (pipe network/radiator immersed in water) - This system has potential if a closed system is required. If a closed system is not required, the evaporative cooling pond would be more economical. Corrosion of the immersed pipe network would be a significant factor in maintenance.

Cooling Tower - This system is possible the next best alternative to the evaporative cooling pond. This system performance will be limited in areas of high humidity. Another limiting factor is this system's performance is that is dependent on the prevailing environmental conditions. The capital cost of this system is high. It also requires maintenance to control water quality issues.

Costs to Cool Water

Shown below in Table 4 is an indicative cost comparison for the various water cooling systems described above. The costs are shown for two different size systems, being 1,000- and 30,000-head feedlot. The respective flows (@ 50L/day/head) are 0.05 ML/day and 1.5 ML/day. These costs are estimates and are indicative only. Care should be used when applying these figures.

Table 4. Indicative capital cost comparison for systems to cool water.

Cooling System	1,000 Head Feedlot	30,000 Head Feedlot
Cooling Tower	$10,000	$30,000
Evaporative Cooling Pond	$3,000	$10,000
Cooling Grid	$8,000	$25,000
Refrigeration System	$15,000	>$50,000

Trough Design

While the supply water temperature needs to be lowered where possible, there are some trough design and practice measures that could be adopted to help reduce the heating of water.

The trough study undertaken in FLOT.317 (Petrov *et al.*, 2002), carried out at three feedlot sites, has provided an overview and understanding of the factors affecting trough water temperatures. The study found that trough inflow temperatures were typically high (25 to 33°C), which will reduce the ability of cattle to shed heat through consumption of water.

The report highlighted the following:

- Due to overnight atmospheric cooling and thus cooling of stored water (cattle water consumption is low at night), a vertical temperature gradient occurs in troughs. This gradient is removed by mid-morning due to the cattle water consumption rates that are notable around morning feed times.

- A horizontal temperature gradient is formed by the inflow of warmer water during early morning periods. This temperature gradient is also removed by the number of trough turnovers that have occurred by mid-morning.

- The study has shown that concrete troughs do provide better cooling of water during the morning periods than that provided by fibreglass troughs.

- Due to the high turnover rates of water stored within a trough over the day, resident water temperatures are highly dependent on the inflow water temperature. This becomes more critical with smaller trough sizes. The study has shown that the water temperature in troughs with a small capacity (and high turnover rate) is equivalent to the temperature of the inflow water.

- The best means of maintaining lower trough water temperatures is to reduce the temperature of the water supply and to use troughs/materials that limit heat and to protect the jobs.

Atmospheric cooling is when a warm water body cools to the cooler atmosphere. These conditions typically occur at night after the water is heated by solar radiation. The warm water might also come from a bore. This is a natural cooling mechanism which is cheap and reliable if it can be suitably utilised. This concept is to have a day's storage at the trough, allowing it to cool overnight and then be consumed the next day. The problem with adopting this cooling method is the large volumes of water required between cooling events. At least 6,000 litres/day would be required for every 100 cattle.

There are potential benefits of both high and low trough turnover rates. High trough turnovers tend to be common in feedlots, due to large numbers of cattle in a small area accessing small trough volumes. High turnover rates reduce the impact of heating at the trough, making the system temperature more dependent on the inflow temperature. However, adequate trough length needs to be maintained beast to ensure the cattle have ample access to water, which is vital. Low turnover rates can increase the benefit of atmospheric cooling at night. Regardless the trough design needs to reduce any heating of the water.

Covering the troughs with some form of shade, or putting the water troughs under the shaded areas will reduce the heat loading on the water and the trough. The area around the trough will have to be considered, as it will stay wet longer. To counter these impacts the concrete aprons may have to be larger and more careful design of the shades required.

Water reticulation through the troughs might help to minimise the temperature increase of the water. The reticulation system could be activated by several parameters including time or temperature. A time-activated system would limit the time the water was in the trough being heated from the sun. A temperature activated system could be set-up with a thermostat to reticulate the water once the temperature in the trough increased above a nominated value. Discharged water could be used for secondary purposes; dust controls, spray cooling, ensuring water is not wasted.

DISCUSSION AND EVALUATION

Evaluation of the Effect of Drinking Water Temperature

The effects of drinking water temperature have been outlined in previous sections. However the magnitude of the effects needs to be quantified.

The water consumed absorbs heat from the animal, if the water temperature is less than the animal body temperature. The amount of heat transferred depends on the amount of water consumed and its temperature determined by Equation 4 below. A comparison of drinking water temperatures are outlined in

$$Q = mC(T_2-T_1)$$ **Equation 4**

where

m = mass of water (kg),

C = specific heat, for water C = 4180 J/°C.kg,

T1 = final temperature (°C),

T2 = initial temperature (°C).

Assuming the cattle drink 60 litres of water per day and their average body temperature is 39°C, the relative heat losses are as described in Table 5 below.

Table 5. Effect of drinking water temperature

Temperature of Supply (°C)	Energy Loss (MJ/day)
35	1.00
30	2.26
25	3.51
20	4.77
15	6.02
10	7.27

From the calculations in Table 5 above, we can see that only 1.00 MJ of energy is transferred from the animal to water at 35°C. If this water had been cooled to 10°C, then the energy transfer would have been 7.27 MJ, almost a ten-fold increase.

Supplying cool water for drinking thus has a limited, but important direct cooling effect. The other benefits associated with drinking cooler water have a significant impact in reducing heat stress, making it a very worthwhile practice. This includes; increased water uptake, improves feed conversion, reduces illness, improves cooling ability and improves body functions. It also maximises their cooling ability through sweating, breathing and decreasing body temperature.

From this information it should be noted that water above 35°C should never be supplied to cattle. As water temperature increases above 35°C the water stops becoming a heat loss mechanism to becoming a heat source. If the water source is from a bore, and is hot, the water must be cooled.

It is recommended that water be supplied ideally at 16-18°C and definitely less than 25°C.

Evaluation of Sprinkler Cooling Systems

System Design

The design combinations of these systems can vary infinitely, so the following system that is outlined is what is most commonly mentioned in the literature and the general noted recommendations for the dairy industry within USA. These regions typically have high humidity, so they might not be applicable here in Australia. It is a fully automated and fixed system.

The system generally includes:

- controller (timer) and thermostat;
- 180^o and/or 360^o sprinklers;
- pressure regulator;
- in-line filter;
- pressure gauge;
- pipe, connections and fittings, valves etc.

In dairy cooling systems sprinklers are set-up above the cattle. The height range is from 2.4 to 4 m. Low pressure systems are preferred (~10 psi) to achieve a large droplet. The larger droplet better penetrates the hair layer wetting the cattle through the hair to the skin. Several sources (Holmes, 1996, Worley, 1999) suggest approximately 30- to 60-minute operating cycles, but need to be adjusted depending on the conditions. Each cycle the volume of water applied range from 2 to 6 mm. The recommended application time of about 0.5 to 3 minutes, allowing the water to soak into the hair through to the skin. The remaining time of the cycle allows for the applied water to evaporate, so the animal is dry before the next application starts. The systems ideally have a thermostat control for activation once the temperatures reach over a preset value. (Holmes *et al.*, 1996) recommend the thermostat values be set between 24 and 27°C. These values are extremely low for Australian feedlot conditions. A more suitable temperature for feedlots within Australia is 35°C.

While spray cooling is an effective cooling method, it has some negative impacts and requires a lot of infrastructure and should only be used when needed. When temperatures exceed 35^oC the cattle's natural cooling mechanisms are significantly reduced and much greater heat loss mechanisms are needed. It is recommended that spray cooling is used when ambient temperatures exceed 35^oC.

This system uses an appreciable amount of water when cooling a herd. To effective cool cattle about 4 mm of water needs to be applied into the hide. Assuming 5 mm of water was applied, allowing for 20% of applied water to drain of the hide. If the stocking density of the feedlot is 15m^2 per animal, then 75 L/animal/application would be applied. For a 20,000-head feedlot this would require 1.5 ML of water for each application. This system also requires a properly sloping floor, preferably concrete, to handle the increased drainage requirement. The water treatment system will also have to handle this extra drainage.

Not all scenarios could warrant a full system as outlined above, as the cost is significant. Intermediate measures might be an alternative option, which cost significantly less. These measures might be as simple as having a mobile water cart carrying cool water and spraying the water onto the cattle using a big gun. This method has some advantages and disadvantages. This has the advantage of the operator being able to apply the correct amount of water for the given conditions. The disadvantage of this system it is very labour intensive. This system is management dependent.

Effects of Spray Cooling

While the effects of spray cooling have not been quantified, the magnitude of the effects needs to be calculated. The heat loss from the animal is transferred to heating the water applied and evaporating it. The amount of heat transferred depends on the number of applications per day and the amount of water applied in each application. The calculations below are based on the heat loss per application.

Assumptions:

Weight of the cattle is 600 kg.

Cattle's average body temperature is 38.5°C.

Surface area is 5 m^2, with an effective wetted area of 1.5 m^2.

Amount of water applied per application is 4 mm.

So the volume of water effectively applied:

$$Vol_{EFFECTIVE} = \text{Water Applied} * \text{Effective Area}$$
$$= 0.004 * 1.5$$
$$= 0.006m^3 \text{ or 6 litres} = 6 \text{ kg of water.}$$

In this process the two types of heat transfer are calculated separately (sensible and latent heat).

$$Q_{SENSIBLE} = mC(T_2 - T_1)$$ **Equation 5**
$$= 6 * 4180 * (38.5 - 25)$$
$$= 0.34 \text{ MJ}$$

$$Q_{LATENT} = mL_v$$ **Equation 6**

where

m = mass of water (kg),

L_v = Latent Heat of vaporisation (for water at 25°C is $2.44*10^6$J/kg)

$$Q_{LATENT} = 6 * 2.44*10^6$$
$$= 14.64 \text{ MJ}$$

$$Q_{TOTAL} = Q_{SENSIBLE} + Q_{LATENT}$$ **Equation 7**

$$Q_{TOTAL} = 0.34 + 14.64$$
$$= 14.98 \text{ MJ}$$

For every spray cooling application 15 MJ of energy is dissipated from the animal. In extreme heat conditions, up to nine cooling applications could be applied in a day (based on as hourly cycle operating from 9 am til 6 pm). This would mean 135 MJ of energy are dissipated from the animal. This amount of energy dissipation is potentially huge, giving spray cooling enormous potential as a method of cooling. With this amount of possible energy dissipation it can minimise the impacts of heat stress events. Spray cooling has the largest cooling potential of all cooling systems for cattle, above shade and diet modification, but is limited by water supply and environmental conditions.

Operating Constraints

A significant limitation to spray cooling is the establishment cost. Setting up a full system might not be economical in all circumstances. Each situation needs to access its options and work out what is required. In some cases there might have to be a new water source, cooling system, water pumping and reticulation system, and concreting the area under shade. Intermediate measures, which cost significantly less, might be an alternative option. These measures might involve a partial system, or even combining this cooling system with the dust control system.

There is a significant management requirement and knowledge base needed to operate these systems efficiently and effectively. Somebody needs to determine when the cooling system will operate and how it should operate for in the given conditions. This will possibly require monitoring the environmental conditions and interpreting them. A lot of work has been conducted on heat stress indexes and how they relate to heat stress.

There are several physical factors, which limit the system including adequate water supply, size of wastewater system and existing infrastructure. This system uses a lot of existing infrastructure and generally requires a lot of extra capacity in this infrastructure. This extra capacity is not always available and upgrading might be required. Maintenance is another issue that needs to be considered.

In feedlots the sprinklers need to be carefully positioned so they do not wet the feed, but maximise the number of cattle being suitable wetted. The amount of ground wetted needs to be minimised. The sprinklers, in all cases, should be set-up in areas where cattle accumulate in times of hot weather, like under shade. The back corner of pens has proved to be a good position for sprinklers. There needs to be good drainage on the wetted area to prevent wet boggy areas.

The pen area versus cattle density needs to be considered. If the density is very low it could create problems of where the sprinklers are set-up and how many cattle they actually water. The system would be extra large and water wastage would be high, increasing the negative impacts. Alternatively if the density were excessively high it would prevent airflow, increasing humidity. Ideally the cattle would be close together while the water is being applied, minimising water wasted, then be able to spread out through the drying phase to increase airflow, which would reduce the increase in humidity as a result of spray cooling. However, this is not possible and the chosen density of the cattle needs to be compromise that suits the existing layout.

Optimum Temperature for Water to be Supplied/Sprayed onto Cattle to Reduce Heat Stress

The optimum water temperature needs to ensure the cattle’s natural responses and mechanisms for cooling are maintained, while not contributing to heat stress symptoms. The temperature at which heat stress symptoms start is 25°C, so the temperature of water applied should not exceed this value. To maximise efficiency and save cooling costs, the water-cooling needs to be minimised. At a water temperature of 25°C, this will maintain the cattle’s natural cooling mechanisms, while not contributing to heat stress and also minimising the amount of cooling. From the calculations above we see that the majority of heat loss is from latent heat of evaporation. As a result the recommended temperature to apply water is ideally at 16-18°C and definitely less than 25°C.

The Impact Spray Cooling Has on the Pen Microclimate and Feedlot Environment

Spray cooling can have significant negative impacts on the pen microclimate and feedlot environment if construction and management is not appropriate for the given circumstances. Management of a spray cooling system is vital for the benefits to out-weigh the impacts. This system needs to be operated according to the prevailing conditions. The amount of time the sprinklers operate and the time allowed for drying significantly affects the performance of the system. To maximise the cooling of the system, these timings need to be optimised. If the sprinkler operating time is not long enough and/or the drying time is excessive, the system is under-performing. Or, alternatively, if the sprinkler operating time is excessive and/or the drying time is not long enough, water is being wasted which has negative impacts on the system.

Spray cooling adds water into the system that increases relative humidity. At times of low wind speed (which is common in times of excessive heat) this increase in relative humidity becomes very significant. If the ground becomes wet this leads to greater odour and ammonia production. The increase in ammonia further increases the stress in the cattle. All these impacts are increased if the spray cooling occurs under shade. This is as a result of lower wind speed under the shade structure and the wetted ground taking longer to dry. This increase in relative humidity can be compensated by increased airflow to remove excess moisture.

While spray cooling has some impacts that are not desirable, there are some extra benefits. Excess water applied to the cattle will also help with dust control. The dust control system and the spray cooling system might even be able to be combined into a single system. Spray cooling will be when dust control is most needed. Another benefit in wetting the ground is that it reduces the soil temperature. This helps reduce the temperature of the environment as well as creating a heat sink.

CONCLUSIONS

Cool Water

Supplying cool water for drinking has a limited but important direct cooling effect. The other benefits associated with drinking cooler water have a significant impact in reducing heat stress, making it a very worthwhile practice. This includes; increased water uptake, improves feed conversion, reduces illness, improves cooling ability and improves body functions. It also maximises an animal's cooling ability through sweating, breathing and decreasing body temperature.

It is recommended that water be supplied at 16-18°C, but below 25°C. Water temperatures above 25°C add to the heat stress of the cattle and where possible should be avoided.

Spray Cooling

The majority of heat loss resulting from spray cooling is from latent heat of evaporation. Sensible heat loss only accounts for a small contribution, 0.34 MJ compared to 14.64 MJ (T_a=25^{o}C, RH=<65% and water temperature of 25^{o}C). The temperature of the applied water has a small effect on cooling, but it also affects the cattle's natural cooling mechanisms. As a result the recommended temperature to apply water is 25^{o}C.

This amount of energy dissipation is huge, giving spray cooling enormous potential as a method of cooling. With this amount of possible energy dissipation it can counter all heat stress events. Spray cooling has the largest cooling potential of all cooling systems for cattle, above shade and diet modification.

Spray cooling can have significant negative impacts on the pen microclimate and feedlot environment if construction and management isn't appropriate for the given circumstances. Spray cooling adds water into the system, which increases relative humidity. It times of low wind speed (which is common in times of excessive heat) this increase in relative humidity becomes very significant. If the ground becomes wet this leads to greater odour and ammonia production. The increase in ammonia further increases the stress in the cattle. All these impacts are increased if the spray cooling occurs under shade. This increase in relative humidity can be compensated by increased airflow to remove excess moisture.

Water Cooling

Evaporative cooling ponds have the most potential as a cooling system for providing cool drinking water to feed-lot cattle, as it is the most cost effective and efficient cooling system. There needs to be further basic research to determine operating constraints and quantify temperatures and possible heat dissipation. This system can also act as a balancing storage, which can be enhanced by shading. Most feedlots would already have a water storage that could be used as an evaporative cooling pond.

While the supply water temperature needs to be lowered where possible, there are some trough design and practice measures that could be adopted to help reduce the heating of water. These include; increasing trough turnover to minimise the heat at the trough, covering the troughs to reduce incoming solar radiation, water reticulation through troughs, and/or maximise atmospheric cooling at night by increasing trough size, trough materials and reducing the sheer thermal mass of the trough.

RECOMMENDATIONS

- Cool water needs to be supplied to cattle for drinking. While cool water has a limited direct cooling effect, other benefits associated with drinking cooler water have a significant impact in reducing heat stress. This includes; increased water uptake, improves feed conversion, reduces illness, improves cooling ability and improves body functions. It also maximises their cooling ability through sweating, breathing and decreasing body temperature.

- Drinking water should be supplied to cattle at 16-18°C and definitely less than 25oC to minimise heat stress. If the drinking water temperature is above 25oC, options for cooling need to be investigated and adopted. The temperature of the supplied drinking water should also be consistently cool.

- When ambient air temperatures exceed 35oC and when the relative humidity is less than 60% (Tw = 28°C) spray cooling needs to be considered as a cooling mechanism to alleviate heat stress in the cattle. The water temperature used for of spray cooling cattle should be 25°C.

- When spray cooling cattle to alleviate heat stress, ensure the cattle are thoroughly wet to the skin. This is achieved by using large water droplets and ample quantities of water.

- Spray cooling cattle needs to be carefully managed by metering application rates to avoid significant negative impacts.

- The drinking water supply needs to be good quality and available in ample quantities with adequate access.

- Modify trough design and practice measures to reduce heating at the trough. This could be achieved by shading, reducing thermal mass of the trough and maximise atmospheric cooling at night.

- Evaporative cooling ponds have the most potential as a large scale cooling system for providing cool drinking water to feed-lot cattle.

RECOMMENDATIONS FOR FURTHER RESEARCH

Thermal Properties of Water Storages and Their Suitability for Cooling

Evaporative cooling ponds could be a very effective, yet cheap method of cooling water. It requires minimal capital cost and very low operating and maintenance costs. The management of this system is very low. While this system has enormous potential benefit for the beef industry it needs further research to determine its operating constraints and optimum design. Things that need to be determined are: temperature gradient *versus* depth of storage, influencing factors of temperature gradient, possible heat loss, potential cool water temperature, storage volumes and depths required and possible problems. Other things that could be considered are the options of enhancing this system, such as shading or covering the pond and the effects of these enhancements.

Cooling Water at the Trough

One key systemic problem is that the water is reticulated through a large network of pipes which, if the ground is warm, acts as a heat exchanger with the result that the ground heats the water. In such a circumstance, cooling water at the trough is the only plausible means of providing a trough with cool water. Simple means of trough water cooling should be investigated.

REFERENCES

Bartlett, D.A. (1996), 'The Fundamentals of Heat Exchangers', *The Industrial Physicist*, American Institute of Physics, pp. 18-21. http://www.aip.org/tip/INPHFA/vol-2/iss-4/p18.pdf (accessed November 2002)

Barnes, A., Beatty, D., Taylor, E., Pethick, D., Costa, N., Maloney, S., Stockman, C., Toovey, A., McCarthy, M., White, C. & Masters, D. (2002). *Live.209 Physiology of Heat Stress In Cattle*, Meat and Livestock Australia, North Sydney.

Boyles, S. (n.d.) *Livestock and Water*, Ohio State University. http://beef.osu.edu/library/water.html (accessed Nov 02)

Brouk, M. J., Smith, J.F. & Harner, J.P. (2001) 'Efficiency of Modified Evaporative Cooling in midwest Dairy Freestall Barns' in *Livestock Environment VI: Proceedings of the Sixth International Symposium* pp. 412-417. ASAE, Michigan.

Davis, M.S., Mader, T.L. (2001) 'Effects of Water Application to Feedlot Mounds during the Summer' in *Livestock Environment VI: Proceedings of the Sixth International Symposium* pp. 165-172. ASAE, Michigan.

Department of Science and Technology & the Bureau of Meteorology (1975). *Manual of Meteorology; General Meteorology*, Australian Government Publishing Service, Canberra.

Esmay, M.L. (1969) Principles of Animal Environment: Environmental Engineering in Agriculture and Food series, AVI Publishing Company Inc., Westport.

Flamenbaum, I., Wolfenson, D., Mamen, M., Berman, A. (1986) Cooling Dairy Cattle by a Combination of Sprinkling and Forced Ventilation and its Implementation in the Shelter System, *Journal of Dairy Science* Volume 69, pp. 3140-3147.

Gaughan, J.B., Kunde, T.M., Mader, T.L., Holt S.M., Lisle, A., Davis, M.S. (2001) 'Strategies to reduce High Heat Load on Feedlot Cattle' in *Livestock Environment VI: Proceedings of the Sixth International Symposium* pp. 141-146. ASAE, Michigan.

Gaughan, J., Young, B., Goodwin, P., Huth, J. (1997) 'A Device for Detecting Periods of High Heat Load in Animals', in *Livestock Environment V: Proceedings of the Fifth International Symposium* pp. 195-202. ASAE, Michigan.

Gebremedhin, K.G., Ni, H., Hillman, P.E. (1997) 'Temperature Profile and Heat Flux Through Irradiated Fur Layer', in *Livestock Environment V: Proceedings of the Fifth International Symposium* pp. 226-233. ASAE, Michigan.

Gebremedhin, K.G., Wu, B. (2002) Simulation of Sensible and Latent Heat Losses from Wet-Skin Surface and Fur Layer, *Journal of Thermal Biology* Volume 27, pp. 291-297.

Hahn, G.L., Mader, T.L. (1997) ‘Heat Waves in Relation to Thermoregulation, Feeding Behavior and Mortality of Feedlot Cattle’, in *Livestock Environment V: Proceedings of the Fifth International Symposium* pp. 563-571. ASAE, Michigan.

Hahn, L., Mader, T., Spiers D., Gaughan, J., Nienaber, J., Eigenberg, R., Brown-Brandl, T., Hu, Q., Griffin, D., Hungerford, L., Parkhurst, A., Leonard, M., Adams, W., Adams, L. (2001) ‘Heat Wave Impacts on Feedlot Cattle: Considerations for Improved Environmental Management’ in *Livestock Environment VI: Proceedings of the Sixth International Symposium* pp. 129-139. ASAE, Michigan.

Harricharan, H. (1999). ‘Keep the Water Flowing’ OMAFRA. http://www.gov.on.ca/OMAFRA/english/livestock/dairy/facts/info_keep.htm. (accessed December 2002)

Hicks, R. B., Owens, F. N., Gill, D. R., Martin, J. J. & Strasia, C. A. (1988) Water Intake by Feedlot Steers, Animal Science Research Report, Agricultural Experiment Station, Oklahoma State University, 1988, No. MP-125.

Hillman, P. & Gebremedhin, K. (1997) ‘A Portable Calorimeter to Measure Heat Transfer from cattle hair Coats’, in *Livestock Environment V: Proceedings of the Fifth International Symposium*, pp. 202-209. ASAE, Michigan.

Hillman, P.E., Gebremedhin, K.G., Parkhurst, A., Fuquay, J., Willard, S. (2001) ‘Evaporative and Convective Cooling of Cows in a Hot and Humid Environment’ in *Livestock Environment VI: Proceedings of the Sixth International Symposium,* pp. 343-350. ASAE, Michigan.

Holmes, B.J., Massie, L.R. (1996) ‘Spray Cooling Dairy Cows’ University of Wisconsin-Madison. http://cdp.wisc.edu/pdf/spray.pdf (accessed December 2002)

Joel, R. (1971) Basic Engineering Thermodynamics in SI units,

Jones, G.M., Stallings, C.C. (1999) ‘Reducing Heat Stress for Dairy Cattle’ Virginia Technology. http://www.ext.vt.edu/pubs/dairy/404-200/404-200.html (accessed December 2002)

Leonard, M.J., Spiers, D.E., Hahn, G.L. (2001) ‘Adaptation of Feedlot Cattle to Repeated Sinusoidal Heat Challenge’, in *Livestock Environment VI: Proceedings of the Sixth International Symposium*, pp. 119-128. ASAE, Michigan.

Lofgreen, G.P., Givens, R.L., Morrison, S.R., Bond, T.E. (1975) Effect of Drinking Water Temperature on Beef Cattle Performance, *Journal of Animal Science*, Volume 40 No. 2, pp. 223-229.

Marley Cooling Technologies, Inc., (1986), ‘Cooling Tower Performance, Basic Theory and Practice’.

Mitlohner, F.M., Galyean, M.L., Patterson, J.B., Nunnery, G.A., Salyer, G.B., Morrow-Tesch, J.L., Dailey, J.W., McGlone, J.J. (2001), ‘Shade and Water Application to Decrease Heat Stress of Heifers in an Experimental Feedlot’, Burnett Centre Internet Progress Report.

Nienaber, J.A., Hahn, G.L., Eigenberg, R.A., Brown-Brandl, T.M., Gaughan, J.B. (2001) ‘Feed Intake Response of Heat Challenged Cattle’, in *Livestock Environment VI: Proceedings of the Sixth International Symposium*, pp. 154-164. ASAE, Michigan.

Oke, T. R. (1987) *Boundary Layer Climates*, Wiley and Sons, New York.

Pannkoke, T. (1996), ‘Cooling Tower Basics’, HPAC(Heating/Piping/Air Conditioning), pp. 137-155. http://www.hpac.com/member/archive/pdf/1996/0296/cooltowr.pdf (accessed November 2002).

Petrov, R., Lott, S, & Cork, R. (2001) Measuring Microclimate Variations In Two Australian Feedlots, MLA Project Number FLOT.310 Final Report, Meat and Livestock Australia Ltd, North Sydney.

Petrov, R., Lott, S, & Cork, R. (2002) Measuring The Microclimate of Eastern Australian Feedlots, MLA Project Number FLOT.317 Final Report, Meat and Livestock Australia Ltd, North Sydney.

Shearer, J.K., Bray, D.R. & Bucklin, R.A. (1999), The management of heat stress in dairy cattle: what we have learned in Florida, in "The 1999 Proceedings of the Virginia Tech Feed and Nutritional Management Cow College", Virginia Polytechnic Institute, VA., pp. 60-71. http://www.dasc.vt.edu/nutritioncc/index99.html (accessed November 2002)

Smith, J.F., Harner, J.P., Brouk, M.J. (2001) 'Keeping Cows Cool, Where Do I Start?', Kansas State University. http://www.oznet.ksu.edu/library/lvstk2/ep77.pdf (accessed November 2002)

Sparke, E.J., Young, B.A., Gaughan, J.B., Holt S.M. & Goodwin, P.J. (2001) Heat Load in Feedlot Cattle, MLA Project FLOT.307,.308,.309, Meat and Livestock Australia, North Sydney.

Thompson-Turner, L.W., Warner, R.C., Chastain, J.P. (1997), 'Micro-Sprinkler and Fan Cooling for Dairy Cows: Practical Design Considerations', University of Kentucky. http://www.ca.uky.edu/agc/pubs/aen/aen75/aen75.pdf (accessed Nov 02)

Winchester, C. F. & Morris, M. J. (1956) Water Intake Rates of Cattle, *Journal of Animal Science* Volume 15, pp. 722-740.

Worley, J.W. (1999), 'Cooling Systems for Georgia Dairy Cattle', University of Georgia. http://www.ces.uga.edu/pubcd/b1172-w.html (accessed November 2002)

Young, B.A., Hall, A.B., Goodwin, P.J., Gaughan, J.B. (1997) 'Identifying Excessive Heat Load', in *Livestock Environment V: Proceedings of the Fifth International Symposium*, pp. 572-576. ASAE, Michigan.

Young, H. D. (1992) *University Physics*, Addison-Wesley Publishing Company, Inc., New York.

Young, H.D. & Freedman, R.A. (1996). *University Physics*, 9th edition, Addison-Wesley Publishing Company, Massachusetts.

APPENDICES

Appendix A – Contract Agreement

Consultant

Company

Name:	E.A. Systems Pty Limited
ABN:	67 081 536 281
Street Address:	CKR House Cinders Lane ARMIDALE NSW 2350
Postal Address:	PO Box W1029 ARMIDALE NSW 2350

Contact

Name:	Dr Simon Lott
Position:	Managing Director/Principal Environmental Engineer
Telephone:	(02) 6771 4864
Fax:	(02) 6771 4867
E-mail:	info@easystems.biz

Services

Title

FLOT.322 - Managing Heat Stress – Weather Stations, Pen Manure Management and Cooling Drinking Water

Background

The feedlot industry has recently undertaken research on the effects of various factors, including ration and shade on the heat loading of cattle (MLA Project FLOT.314 and FLOT.315). Other work has been undertaken on defining the microclimate of feedlots through projects MLA FLOT.310 "Measuring Micro-climate Variations in Two Australian Feedlots" and FLOT.317 "Measuring the Micro-climate Variations of Eastern Australian Feedlots".

The work has been linked to other projects aimed at assessing animal comfort and the effects of animal type, age and factors such as coat colour on heat load and subsequent stress. This work continues and there is a need to ensure that meteorological data collected as part of these projects is sound.

Part of Project FLOT.317 studied the temperature of water supplied to lot fed cattle in a range of water troughs and also measured the temperature of inflow water and water supplies. The study found that water temperatures were high.

The energy balance of a steer is directly influenced by surplus energy derived from ingested feed, adsorption of radiation, convective losses, evaporative cooling and the temperature of ingested water. The amount of energy required to heat water to body temperature varies as a function of the amount of water drunk and the temperature of the water. The temperature of water provided to stock also influences appetite and thus influences feed intake.

Purpose and Description

This project incorporates a mix of desktop reviews and data collection in feedlots to address a number of the issues that are still unresolved in our understanding of the effects of heat load on feedlot cattle and potential ameliorative actions.

This project will provide the meteorological data required to ensure that the animal observations undertaken in project FLOT.319 'Refinement of the Heat Load Index Based on Animal Factors' can be correlated against the prevailing weather conditions at the time of the observation and ensure the validity of threshold values derived for the onset of heat load induced stress for the various classes of livestock.

Within the feedlot industry there is a lot of confusion about whether spraying cattle is an effective mechanism for relieving heat load under conditions of high humidity and low wind speed. The project will define the conditions under which it is advantageous and disadvantageous to spray cattle that are subject to excessive heat load.

Practical means of cooling water to be supplied to livestock need to be identified. The project will review commercially available technologies for cooling water and assess the practicality and basic economics of their use and provide guidelines for practical application of the technologies in a feedlot situation.

The outcomes of these reviews and other important aspects of pen environmental management and monitoring under extreme weather conditions will be extended to industry through the development of a range of 'Tips and Tools'.

Objectives

The Consultant will achieve the following objective(s) to MLA's reasonable satisfaction:

By 30 April 2003:

1. Service, maintain and calibrate weather stations at two (2) feedlot sites in southern Queensland, with subsequent data collection, collation and packaging, to supply sound data on atmospheric conditions to the research group studying the impact of heat load on various classes of livestock.

2. Develop Industry guidelines on the use of water sprays for cooling of stock under conditions of excessive heat loads, by defining the conditions under which the use of water sprays for cooling of stock would be advantageous and also those conditions under which the use of water sprays would be detrimental.

3. Develop Industry guidelines on the use of water cooling systems for the reduction of heat load in feedlot cattle, by:

   - undertaking a review of the literature on water consumption and commercially available technology on water cooling;
   - quantifying the effects of supplying cool water to stock with respect to energy reduction and modification of appetite and feed intakes;
   - identifying existing technologies used to either prevent heating, maintain water temperature or cool water either in storage or at the point of delivery for consumption;
   - screening these technologies for possible practical application in feedlots for cooling water for supply to water troughs;
   - assess the different systems through an simple economic appraisal and desktop investigation of the technology; and,
   - ranking identifiably useable water cooling systems.

4. Prepare short papers that can be used as extension material for technology transfer to Industry participants, on the following subjects:

   - the maintenance and servicing of weather stations;
   - the management of pen conditions to minimise environmental problems and maximise animal comfort;
   - the use of water sprays for the cooling of feedlot cattle under conditions of excessive heat load; and,
   - the use of water cooling systems for the reduction of heat load in feedlot cattle.

Method

The project will be conducted in a number of stages:

5. Servicing, maintenance and calibration of weather stations with subsequent data collation and packaging,

6. Review of literature of water consumption and commercially available technology on water cooling,

7. Using a systems analysis approach to defining the animal-atmosphere relationship, characterise the effects of spraying cattle with water to achieve evaporative cooling in terms of the amounts of water needed, the effects on feedlot micro-climates and possible consequential environmental issues,

8. Ranking identifiably useable water cooling systems and assessing the practicality and basic economics of their use, and,

9. Preparation of short papers for technology transfer and a Final Report to industry.

The first stage of the project requires an initial inspection, cleaning, testing, and calibration of sensors, logger and weather station structures to ensure that data collection by the station components is competent and if variance is occurring in measurements the calibrations can be used to obtain corrected data. This requires use of special transducers and pre-calibrated sensors to be used in parallel with the site weather stations to generate twin datasets over a defined recording period. The stations will then be serviced on a monthly basis until completion of the project. It is anticipated that this will entail servicing and maintenance in early January, February, and March. A final down load will be undertaken in April.

The second stage of the project includes a small research literature review, a review of commercial equipment and systems, and then an agricultural engineering systems analysis of spraying cattle to achieve evaporative cooling of stock with excessive heat loads. A focused literature review will be undertaken to define the effects of supplying cool water to cattle in terms of potential reductions in energy load and effects on appetite. The second review will investigate the efficacy and practical application of a range of commercial systems to either prevent heating of water, maintenance of cool water temperatures, or actual cooling of water, including but not be limited to:

- pond covers;
- pond surfactants;
- cooling towers;
- pond design and construction techniques;
- trough design, construction and management (eg recirculation systems to limit heating), and
- heat exchangers.

The final review in the first stage will undertake a systematic assessment of the effects of spraying cattle to achieve evaporative cooling and thus a reduction in heat load on:

- the animal, and
- the pen micro-climate and feedlot environment, and changes in it that may affect its environmental performance.

The documentation of the work will define the advantages and disadvantages of spraying cattle in an effort to reduce heat loads. It will assess the methodologies and define clearly the best methods of wetting hides whilst minimising consequential environmental problems and maximising the reduction in heat loads. Climate constraints on use of various wetting methods will be identified.

The second stage will assess each of the water cooling technologies. The assessment will focus on the cost of commercial units, their ability to maximise the supply of cool water both in a physical sense and also in terms of unit costs. The technologies will then be ranked according to cost, ability to supply cooled water and functionality in a feedlot.

The final stage of the project is the reporting the results of the reviews and assessment of commercial technologies. The reporting will be in two parts; a final report to the MLA and an annexure to the final report, which will contain a short paper (~6-8 pages) setting out the findings of the project in simple form for use in extension material to the industry.

Three other short papers will be produced through the project. These papers will provide information on:

- management of manure to improve environmental performance and the feedlot micro-climate;
- use of weather stations in feedlots; and,
- guidelines on the conditions under which water sprays should and should not be used for cooling feedlot cattle exposed to excessive heat load.

Potential Industry Benefit

The energy reduction achieved in the supply of cool water to animals stressed due to excessive heat loads is comparatively small. While this is true, it may however be sufficient to ensure that an animal does not succumb to excessive heat load during periods of extreme weather conditions. This benefit can be achieved either by the supply of cool water for drinking that will adsorb excess heat at ingestion or spraying cool water on the hide and achieving heat transfer and also evaporative cooling. The loss of energy from the animal to the water reduces heat load and thus provides a mechanism for survival in extreme events of discomfort at times of heat stress.

However, inappropriate application of water by spraying under conditions of high humidity could be detrimental to the animal. Therefore, it is important that Industry has guidelines on the conditions under which the use of water should and should not be employed for spraying animals. This project will provide these guidelines and recommend practical methods for cooling the drinking water that can be adopted by feedlot operators.

Communications

The Consultant will ensure that the Services are communicated as follows:

Item	Details	Person responsible and date
Final Report	The report will be written with the end user in mind and should include a section detailing the implications of the research findings to industry. The report will be supplied in both electronic and hard copy (2, one loose leaf) format and may be reproduced and published in the standard MLA style, with due acknowledgment to the Consultant and authors. Final Reports must be submitted in accordance with MLA's style guide (Final Report Guidelines) to be accepted by MLA. MLA will provide Final Report Guidelines on request.	Dr Simon Lott 30 April 2003
Summary Report	The report, of 3-5 pages, will contain key information from the Services. This will be in a format that is suitable for use in the production of a brochure or similar extension material.	Dr Simon Lott 30 April 2003
Interim Report	Brief report communicating the findings of the assessments and ranking of cooling systems together with the two short papers on manure management and weather stations in feedlots.	Dr Simon Lott 28 February 2003
Regular Update	Where required a regular update will be provided, indicating progress on the Services. Information may be used in the MLA monthly magazine (Feedback), or other MLA publications, to keep producers informed of progress.	Dr Simon Lott

Timetable

Start Date: 1 December 2002

Finish Date: 30 April 2003

	Milestone and Achievement Criteria	Date for Completion
	Start Date:	1 December 2002
1	Final Report to be accepted and acknowledged by MLA.	30 April 2003
2	Final Budget Report to be accepted and acknowledged by MLA.	30 April 2003

Note: Milestones are not achieved unless reports are received and accepted by MLA.

Nominated Persons

Name: Dr Simon Lott
Position: Principal Engineer
Telephone: 02 6771 4864
Fax: 02 6771 4867
E-mail: Simon.Lott@easystems.biz

Name: Mr Peter Binns
Position: Principal Scientist
Telephone: 07 4638 7864
Fax: 07 4638 7854
E-mail: Peter.Binns@easystems.biz

Name: Mr Glen Gordon
Position: Agricultural Engineer
Telephone: 02 6771 4864
Fax: 02 6771 4867
E-mail: Glen.Gordon@easystems.biz

Fees and Payment

Performance-based payment

Total Budget = up to $32,846 (GST exclusive)

Date	**Payment Dependent on Milestone**	**Operating Costs**	**Total**
1 December 2002*		$18,206	$18,206
30 April 2003***	1	$14,640	$14,640

*	on signing of this agreement with tax invoice for payment attached.

**	on acceptance and approval of corresponding Milestone report, with tax invoice for payment and copy of receipts attached.

***	on receipt and acceptance of Final Report by the MLA, with tax invoice for payment attached.

Note: money uncommitted at the end of the provision of Services must be returned to MLA

Details of Operating Expenses

Component	Work Details	Cost	Total Cost
Cooling drinking water	Review literature & commercial technologies	$7,200	
	Assessment of technologies	$2,700	
	Reporting – Final report and ‘tips and tools’	$4,500	$14,400
Weather stations	Calibration equipment	$400	
	Travel - Monthly servicing and data collection for two feedlots (4 trips)	$6,077	
	Labour – Data collection, collation, verification and distribution	$3,469	$9,946
Tips and tools	Preparation of short papers including provision of photos and drawings:		
	Pen Manure Management Weather Monitoring In Feedlots	2,500	
	Use of Water Sprays	$2,500	
		$2,500	$7,500
Project administration	Project management and presentation to Heat Load Committee (no travel allowed for)	$1,000	$1,000
PROJECT TOTAL			$32,846

Contributors/Other Funds

Not Applicable

Insurance

Public and Product Liability Insurance	$10 Million
Professional Indemnity Insurance	$5 Million (able to upgrade upon notice)
Workers Compensation	Covered for operations in both NSW and Queensland

Agents/Subcontractors

Not Applicable

Intellectual property

Intellectual property will reside with MLA.

Appendix B – Maintenance and Servicing of Weather Stations

WEATHER MONITORING IN FEEDLOTS

Dr Simon Carl Lott [1,2]

Principal Environmental Engineer, E.A. Systems
Honorary Associate, School of Natural Resources and Rural Science, UNE

Key Recommendations

(a) Use an automatic weather station to record meteorological data in situations where detailed measurements are needed.

(b) Set an objective for monitoring first. Select and collect variables that will provide useful data for licensing or operations at the site.

(c) Locate the weather station in compliance with recommendations in the Australian Standards and Bureau of Meteorology

- The location should be representative of conditions that need to be monitored.
- The site should be clear of buildings, trees etc and protected from stock and wayward machinery.

(d) Select a weather station on the basis of;

- accuracy and reliability of sensors,
- reliability of the overall system
- ease of maintenance and availability of maintenance services
- ease of managing or manipulating data,
- compatibility with communication systems and application software
- cost
- user friendly software,

A compromise must be struck between cost and the quality of the station and its sensors.

(e) Ongoing maintenance and servicing of the station is essential to ensure the integrity of data through regular cleaning of sensors, repair of damage and calibration of sensors. This will come at a cost and must be part of the budget.

Monitoring Weather

Bureau of Meteorology

The Bureau of Meteorology records weather at selected stations across the nation. Various data are collected and at different scales. At many locations only daily rainfall is recorded. In relatively few strategic locations very detailed measurements are made to allow detailed modelling of atmospheric conditions and thus forecasts of weather to be made.

Tapping into the data collected by the BOM is an astute means of obtaining quality records of historical climate data or short-term prognoses of weather. Actual data files can be obtained via the BOM Climate and Consultancy Services in each state through the email or the web (see address below) using a program called “Datadrill”. Weather forecasts can be obtained from a number of BOM locations a few being;

Weather by Fax - 1902 935 255 for satellite maps.

Web Site - <http://www.bom.gov.au/weather Radar tracking of storm movement

Web Site - <http://www.longpaddock.qld.gov.au/SeasonalClimateOutlook> Queensland Department of Natural resources and Mines Long Paddock season outlooks.

Web site – <htttp://www.bom.gov.au> General information and forecasts

Unfortunately, there is a large expanse of rural Australia where few BOM stations exist and if they are local they only record daily rainfall. This means that it is not possible to obtain a detailed historical picture of some local conditions and forecasts may not take local factors into account. In such situations the use of automatic weather stations is well justified to provide accurate recording of local conditions for historical records and real time measurement of ambient conditions for use in management of on ground operations.

Licence Requirements

Some environmental licences and development approvals for feedlots require the operator to collect meteorological measurements. The recordings may be as simple as daily rainfall or as complex wind stability on a 10 minute basis. Automatic weather stations (AWS) located at a feedlot allow remote and digital recording of meteorological measurements.

Feedlots are at times required to keep a formal register of complaints regarding the facility. Complaints are most often related to the impacts of odour and dust on nearby residences.

Development Applications

A new feedlot or a feedlot expansion must provide climate data and at times specialist assessments on hydrology, noise and odour impacts to the approval agency. While the climate data can be obtained from the closest Bureau of Meteorology station it is often the case that no detailed meteorological data local to the site are available. In some states up to 12 months of detailed local weather monitoring is required to assist in assessment of the site.

The NSW EPA guidelines for odour assessments “Assessment and Management of Odour from Stationary Sources in NSW“ require that for development applications where odour impact is expected at least 12 months of meteorological data be collected for the purpose of undertaking odour dispersion modelling using data specific to the site. An Automatic weather Station (AWS) needs to be installed at the site to collect these data even for a short period of time (2-3 months MIN) if the data can be correlated with a nearby BOM station.

Automatic Weather Stations

An Automatic Weather Station is set of equipment built to measure and record specific attributes of the ambient environment See Figure 1. They rely on sensors to measure a physical property or condition through time. Sensors are the heart and sole of the weather station.

As a general rule it can be concluded that; the cheaper the weather station and sensors, the less accurate the data, the more prone the electronics and sensors are to failure and the higher the maintenance costs. It is important to also note that while the software may look great this may indicate a high level of investment in the software by the manufacturer that is not necessarily reciprocated in an investment in the important hardware.

Figure 1. A 2 m Automatic Weather Station.

Sensors

The pivotal component of the sensor is a transducer that is used to convert a signal from one medium, such as temperature of a probe, into an electrical signal. Electronic circuitry either in the sensor itself or in a centralised processor gathers these signals.

The circuitry may adjust the signal for “wander” cause by variation in other ambient conditions (eg temperature effects on the transducer recording relative humidity) and also average the signal through time to ensure that a representative recording is made. Variance (error) in the signal is rectified by application of a calibration curve in subsequent data computations either in the circuitry of by a central data processor.

Because the properties of the probe, and indeed that of the circuitry components, can change, the characteristics of the transducer and signal will alter over time. This underpins the need to have; good quality transducers and sensors, and, regular calibration of sensors to reduce error.

Automatic Weather Stations are able to record a host of different measurements. These include;

- rainfall,
- ambient temperature,

- relative humidity,
- wind speed,
- wind direction,
- incoming solar radiation, and,
- barometric pressure.

Using these data it is possible to calculate a host of important variables. Variables important to the feedlot industry are heat load on stock and potential evaporation. Potential evaporation is a useful variable because it can be used to determine the rate of water loss from irrigation areas receiving waste waters and thus irrigation requirements.

Communications

The communications systems used need to allow ease of data transfer from the AWS to the user. The communication system will depend upon both hardware possibly including mobile phones, UHFs, modems etc and also software. The systems should be reliable, inexpensive and follow standard protocols for data transmission. Most feedlot systems rely on UHF communication systems because they are similar to other telemetry used in agriculture (eg pump control systems) or mobile phone links. Recent advances in data transfer using CDMA GSMs allows remote access to many areas other wise not reachable by a UHF.

Data Management

The capture, retention and subsequent output of data needs to be carefully considered when selecting a weather station. The formats used should be;

Practical	the system should be flexible enough to allow read addition of sensors.
Simple	no specialist programme is needed to decode the stored data for use by the user.
Directly Useable	the data can be directly transferred between application software (eg from a normal ASCII file straight into an excel spreadsheet).
Independent of Manufacturer	the data management is not dependent upon special software specific to a manufacturer that limits transferability of files and data and also competitive behaviour between manufacturers.

The use of standard software and standard formatting allows easy management of data and increased useability and functionality. The BOM has standard data formats and the data collected by a local AWS should be configured to comply with one of these formats.

Siting

An Australian Bureau of Meteorology standard has been developed for the installation of weather stations. It sets out the requirements for the operation and management of weather stations. The Bureau states that a 12m by 12m enclosure be used for layout of the weather station sensors. The fence must be robust enough to ensure that sensors are not damaged by stock.

Where the AWS has sensors that are housed together the area of the enclosure can be reduced. However, it is extremely important to note that the fence must not affect the readings from the sensor (by either shading or influence on wind movement or a rainfall shadow). The minimum suggested area for an enclosure is 5m by 5m.

Another important standard is AS2923-1987 “Ambient Air – Guide for Measurement of Horizontal Wind for Air Quality Applications”. This standard is particularly important where data are being collected for the purpose of odour impact assessments including dispersion modelling. It notes that the station should not be placed near trees, buildings etc and be placed at a distance from the largest obstacle to wind movement in the order of 10 times its height.

Maintenance

The AWS installed at a site should be easy to maintain. Maintenance should be able to be undertaken on the station without affecting the climate record. Fore instance sensors should be able to be unplugged whilst they are being cleaned without affecting the recording of other variables.

The lifetime cost of the AWS should be considered rather than simply its initial purchase cost. The lifetime costs include; initial purchase costs (hardware + software), installation costs, annual maintenance costs, sensor replacement frequency and sensor costs, software update costs, and data loss costs. Typically the lower the initial purchase costs is the higher the ultimate ongoing costs will be including increased lengths of time where little or no useable data is recorded.

It should be noted that frequent maintenance will be required where the AWS is in an aggressive environment. Ideally maintenance is limited to once per quarter or less with sensor replacement every two years or thereabout. Some cheaper stations have less accurate, short life sensors that need to be replaced more frequently than better quality sensors. In this case a cost compromise must be struck between initial costs and ongoing maintenance and repair costs. None-the-less some transducers do degrade and despite quality constraints even the best sensors will need to be replaced.

Poor maintenance comes at the price of loss of data and increased repair costs down the track. Figure 2 shows a dust accumulation on a sensor. The resultant blockage prevented recording of data required by an EPA licence.

Figure 2. A Dust Blockage of a Rain Gauge.

Setting Objectives for Micro-climate Measurements

Clear objectives need to be set for any monitoring of weather conditions in a feedlot. Objectives used by current operators of AWSs in feedlots and their associated farms include;

- collection of weather data (rainfall, wind speed and direction etc) to provide a record in reports to government agencies.
- collection of wind speed and direction data to either, confirm or defend against odour complaint.
- calculation of a heat stress index to provide real time indications of heat load to stock.
- collection of solar radiation, wind, ambient temperature, relative humidity data for the computation of evaporation for the purpose of determining crop water requirements for irrigation purposes.
- collection of soil temperature data to determine planting times for crops.
- collection of barometric pressure and temperature and humidity data to assist in managing feed supply to stock (changes to pressure have been associated with changes in feed intake).

Automatic Weather Stations in Feedlots

Objectives

The objective of using an AWS must be clearly defined and will typically aim to meet one or more of the objectives stated above.

The AWS should be sited in an area that is representative of that of interest. Obviously there may be competing objectives in the sense that the micro-climate of a feedlot is different from that of its associated irrigation farm and therefore either one location of the other must be chosen or possibly two weather stations used.

The site must be kept clear of all future developments that may impact on the micro-climate of the area (eg keep it clear of a possible site for silo construction).

In-pen Weather Stations

In an attempt to measure the actual conditions experienced by cattle in feedlot pens some feedlots have placed a weather station inside the pen area. In recent MLA funded studies the difference between the pen conditions and those outside the feedlot have been defined.

In pen conditions are more humid and less windy that those outside a pen. This occurs as a result of moisture additions to the pen surface through manure deposition and impedance to wind movement cause by the pen structures and possibly shades. Unfortunately, the pen conditions are also extremely aggressive and can cause;

- large dust accumulations on an in sensors,
- corrosive attack by organic matter
- cattle weighing up to 750 kg that crush sensors
- possible rodent attack of wiring
- munching on sensors and wiring alike by galahs and cockatoos,
- electromagnetic fields from welding during pen repairs fusing out sensors and circuitry, and,
- wayward pen cleaning machinery and overly curious pen riders destroying otherwise delicate equipment.

The above results in significantly accelerated rates of wear and tear and damage.

Locating a Feedlot Weather Stations

The best location for an AWS in a feedlot is:

- not in a pen!,
- about 500m from the office in a place readily visible to the feedlot manager
- well away from;
    - the feedmill
    - all stock, stock facilities and stockmen
    - machinery
- In an area representative of the area surrounding the feedlot (eg grassed paddock) with out any trees or building around it.
- An accessible area so that the surrounds can be maintained.

While this weather station will not record the conditions that the stock are experiencing the pens the station will provide quality local data that can be used for the assessment of pen conditions. A number of algorithms are being developed for relating external weather conditions to pen conditions. These algorithms are general in nature in the sense that they have been generated from data sets obtained at four large feedlots each with similar pen configurations, stocking densities and stock.

Maintenance of Feedlot Weather Stations

If the weather station is located to dust generating areas (pens, gravel roads) then the primary maintenance problem is dust accumulation on and in sensors. The minimum recommended service interval is once per quarter with interim wipe down servicing by feedlot staff in extreme seasonal circumstances.

The feedlot environment is none the less aggressive and there is a need to check, service and calibrate sensors on a regular basis. Simple calibration checks should be made by using thermometers (ambient air temperature), sling psychrometers (relative humidity), hand held anemometers (wind speed), a sight compass (wind direction) and other calibrated sensors to benchmark readings.

Sensors should only be returned to the manufacturer when the deviation from the calibration reading is unacceptable. Most good quality sensors simply need recalibration rather than replacement.

Handy Hints

- Purchase a station for accuracy, reliability and ease of data management rather than pretty software.
- Use a simple communication system that is reliable and not dependant upon special software.
- Download the data on a regular basis.
- Use the data as much as possible to get the best return from the investment (once the data is used regularly the true worth of the station will be realised).
- Have the station serviced on a regular basis by someone independent that is able to provide infield checks of sensor competence.
- Ensure that the weather station is installed in a manner that prevents access by mice or attack to elevated cables by birds.

Do Not

- put the station near a boundary fence where neighbours can play with the rain gauge - the rain fall data will always be lower than you expect.
- weld near the weather station - this may blow it up.
- let someone with a lawn mower or wiper snipper near it until all cables are located and moved out of the way - cut cables are the best short you can get to loosing data.
- put the station near large metal objects that attract lightning - this is the best frying system nature invented.
- let a novice researcher within 10 km's of the station - a little bit of knowledge can be very damaging.
- believe all of the data the station collects for the above reasons.

Key Contacts

For more information about this call E.A. Systems on 1800 000 864.

APPENDIX C – MANAGEMENT OF PEN CONDITIONS TO MINIMISE ENVIRONMENTAL PROBLEMS AND MAXIMISE ANIMAL COMFORT

PEN MANURE MANAGEMENT

Dr Simon Carl Lott [1,2] , and Glen Gordon[3]

1 Principal Engineer (Ag and Env), E.A. Systems.
2 Honorary Associate, School of Natural Resources and Rural Science, UNE.
3 Engineer (Ag), E.A. Systems

Key Recommendations

(a) Design and managed pens so they have a uniform smooth slope of 2-4% to allow prompt drainage of pens

(b) Design the pens for ease of cleaning

(c) Maintain pens with an interface layer of manure

(d) Pen manure depths should be kept shallow and maintained in a smooth compact condition where possible.

(e) Relate the stocking density to climatic conditions – in wet climates use a density where stock are well spaced out.

(f) To achieve a Class 1 cleaning frequency clean pens at between 8 and 10 weeks if a stocking density of 10m^2/SCU is used.

Pen Design

Pens should be designed to provide good condition for stock, long life of the yard, minimal environmental effects and ease of cleaning, manure harvesting and maintenance. To achieve these objectives several simple design principals should be applied.

- No pen to pen drainage,
- Pen slopes of 2-4%,
- Pen surfaces should be constructed with non expansive clay materials,
- Smooth uniform pen slopes,
- 3m concrete aprons around feed bunks and water troughs,
- Use a trough sewer system that passes water directly to the sediment basin, and
- Feed bunk apron gates for easy cleaning of aprons.

Manure Profile Layers

Stocking of pens results in a layer of manure accumulating on the soil surface of the feedlot. Several layers develop a pen manure profile on, and in the top of the soil profile as a result from the organic animal waste. The layers are the 'top' layers of manure that are exposed to the atmosphere, the 'basal' layer, 'interface' layer and then the very topmost soil beneath the manure pack. These are shown in Figure 6.

The manure profile (top and basal layers inclusive) has a bulk density of 750-930 kg/m3. Immediately below this layer the compacted interface layer had a density of 1000-1700 kg/m3. The underlying soils typically have a density of 1200-1600 kg/m3.

As manure is deposited and accumulates on the pen surface, decomposition occurs by physical and microbiological processes. Urine and solid manure have significant sodium and potassium contents that influence the electrical charges of clay soil particles and cause them to disperse. The trampling of the cattle on the soil surface compacts the dispersed soil particles into the dense, poorly aerated the 'interface' layer. Apart from the physical compaction of the mixed soil and manure particles of this interface layer, microbial decomposition produces by-products such as organic gels and polysaccharides that reduce water infiltration by plugging the soil pores. The interface layer appears to develop regardless of soil type and climate.

The layer effectively acts as a seal that prevents percolation of water through the manure pack and into the soil. Rain falling on the feedlot either leaves as runoff, or is absorbed for later removed by evaporation. This zone of low percolation restricts leaching of salts, nitrates and ammonium into the subsoil and potentially to ground water. Saturated hydraulic conductivity above, and at, the interface layer range from 0.04 to 0.23 mm/day (Southcott et al., 1997).

Pen Conditions and the Environment

Conditions on the surface of feedlot pens change through time, due to evaporation, rainfall, stocking density, cattle trampling (which has different effects depending on the moisture content) and manure management practices.

Each condition depends on manure moisture content and mechanical disturbance of the surface manure by cattle movement. Pen conditions can be grouped into four types being:

(1) powdery-smooth-dry (very dry and dusty conditions);

(2) smooth-compact-moist (slightly moist and well compacted);

(3) rough-wet (wet and pugged by cattle);

(4) smooth-saturated (a slurry - structural collapse of manure).

Figures 1 to 4 show these pen conditions.

Figure 1. Condition 1 – Powdery Dry Pen Conditions.

Figure 2. Condition 2 – Smooth Compact Pen Conditions.

Figure 3. Condition 3 – Wet Pugged Manure Pen Conditions.

Figure 4. Condition 4 – Saturated Slurried Pen Condition.

These conditions affect the roughness of the pen surface. Aside from the pen manure condition, pen slope and rainfall characteristics also influence the pen surface water balance. Figure 5 shows the conceptual water balance of a feedlot pen. The water balance accounts for the additions and losses of moisture from the pen surface. The manure on the pen surface represents a store of water and its characteristics (slope and roughness) may influence its water balance and the rainfall-runoff process from the pen surface. The parameters of interest, when understanding the water balance of the manure are:

- stored water;
- infiltration;
- depression storage/surface retention;
- losses (total and temporary storage);
- evaporation;
- surface runoff.

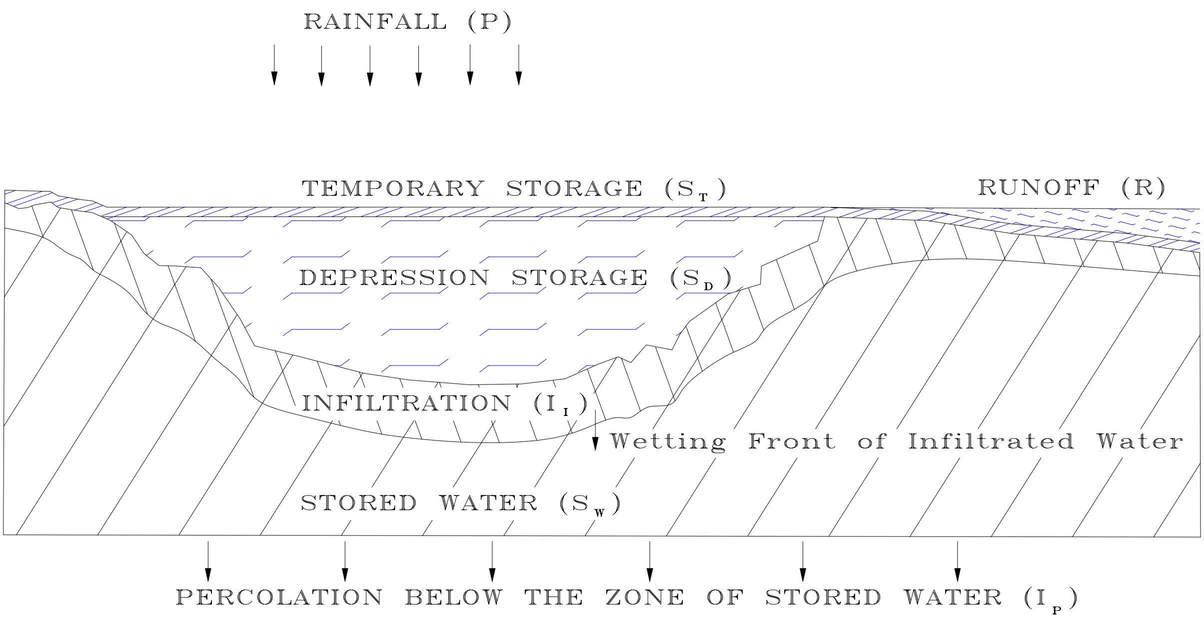


Figure 5. Conceptual Water Balance of a Feedlot Pen Surface.

A further factor must be included in the water balance of a feedlot pen. A large amount of manure water is added in manure voided by the cattle. This is discussed below.

The generation of odour from pen manures is driven by several key factors. Key variables are; manure moisture content and manure temperature (Lunney and Smith, 1995). Manure moisture content is influenced by:

- stocking density which dictates the amount of manure water added to the pen surface;
- the pen condition which influences the amount of water that can be stored in the pen manure surface;
- days since rainfall;
- the amount of rainfall and duration of the event, and,
- depth of manure which influences the gross amount of water that can be stored in the pen profile.

Therefore these conditions can be linked to different environmental outcomes from the feedlot. For instance:

- maximum dust generation occurs in conditions 1;
- maximum runoff occurs in conditions 2 and 4;
- maximum erosion of manure and sediment deposition in drains and the sediment basin occurs in conditions 1 and 4;
- maximum odour nuisance and least runoff occurs in condition 3, and,
- minimum odour and maximum runoff occurs in condition 2.

Feedlots must aim to keep pens in condition 2 for as much time as possible to limit odour nuisance which may be the largest potential environmental and social impact from the operations if neighbours are in close proximity. It is important to note that when manure depths are kept low and condition 2 is maintained pen runoff is maximised.

Stored Water in Manure

The manure on the pen surface can be a significant store of water and strongly influence the water balance of a pen surface. Manure can be air dried to a moisture content of 6% (wet basis (wb)). Faeces voided by cattle can have a moisture content of 80% wb (ie 1 part solids 4 parts water). A water storage capacity can be calculated given this range of moisture content and an average dry bulk density for the manure profile of 750 kg/m^3. For a depth of 100 mm of dry, compact, manure about 280 mm of water can be stored, because the manure expands when water is stored inside manure particles and in the voids between particles. Therefore, the 100 mm of dry manure may become more than 300 mm of wet manure. Figures 6 and 7 show the layers of the manure and soil profile when the pen is dry and wet.

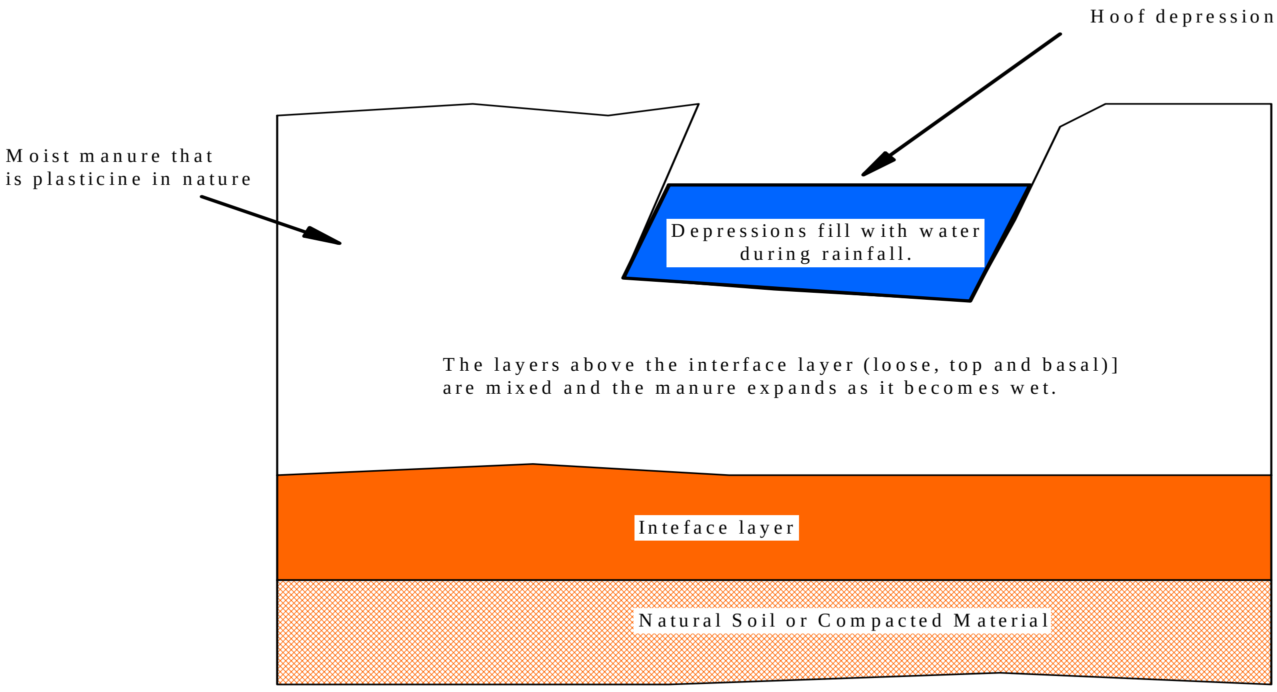


Figure 6. Pad Manure Profile Once It Becomes Wet.

Animal Weight and Manure Generation

Cattle consume dry feed equivalent to about 2.5-3% of their body weight. Water intake is affected by dry feed intake, size of animal and climatic factors. Cattle excrete faeces and urine that, when combined, have a mass equivalent to 5-6 % of the animals body weight.

Lott (1998) presented curves describing the amount of manure and water added to the pen surface as a function of beast weight and stocking density. The curves show an ever increasing addition of excreta with beast weight. Manure water can be a significant component of the water balance of a feedlot catchment. Figure 8 shows the equivalent amount of water added by urine and faeces to the pad each year. As discussed below the curves applicable to manure accumulation have since been disproved and these data whilst not affected to the same degree should only be used as a guide.

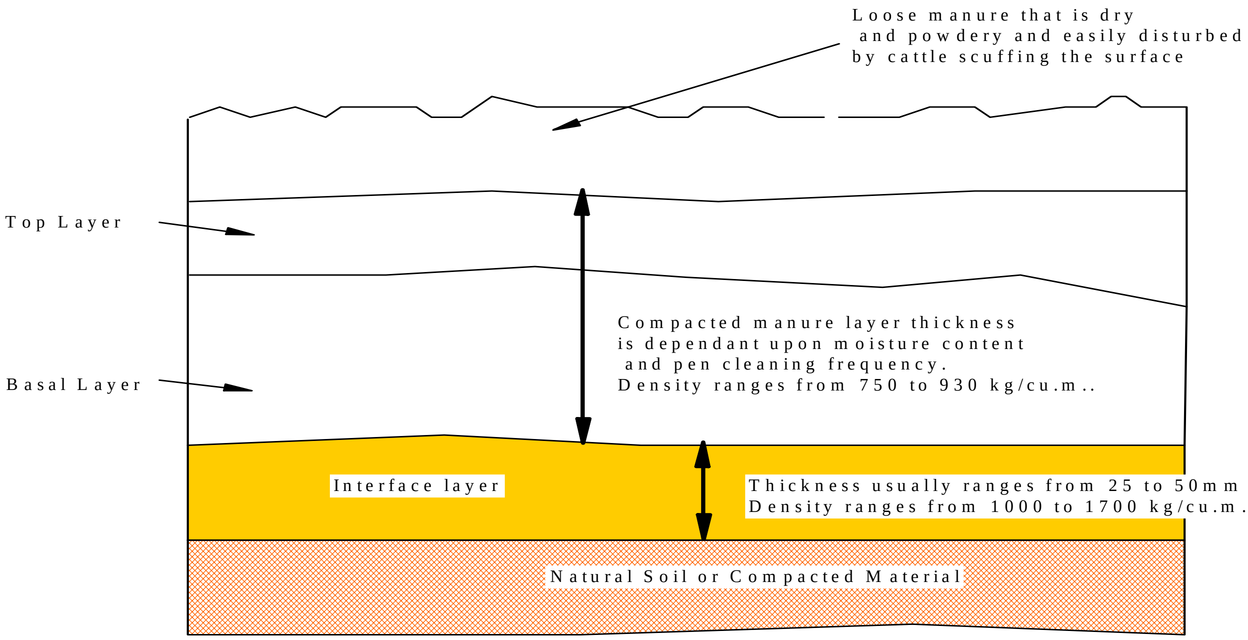


Figure 7. Dry Manure Pad Profile.

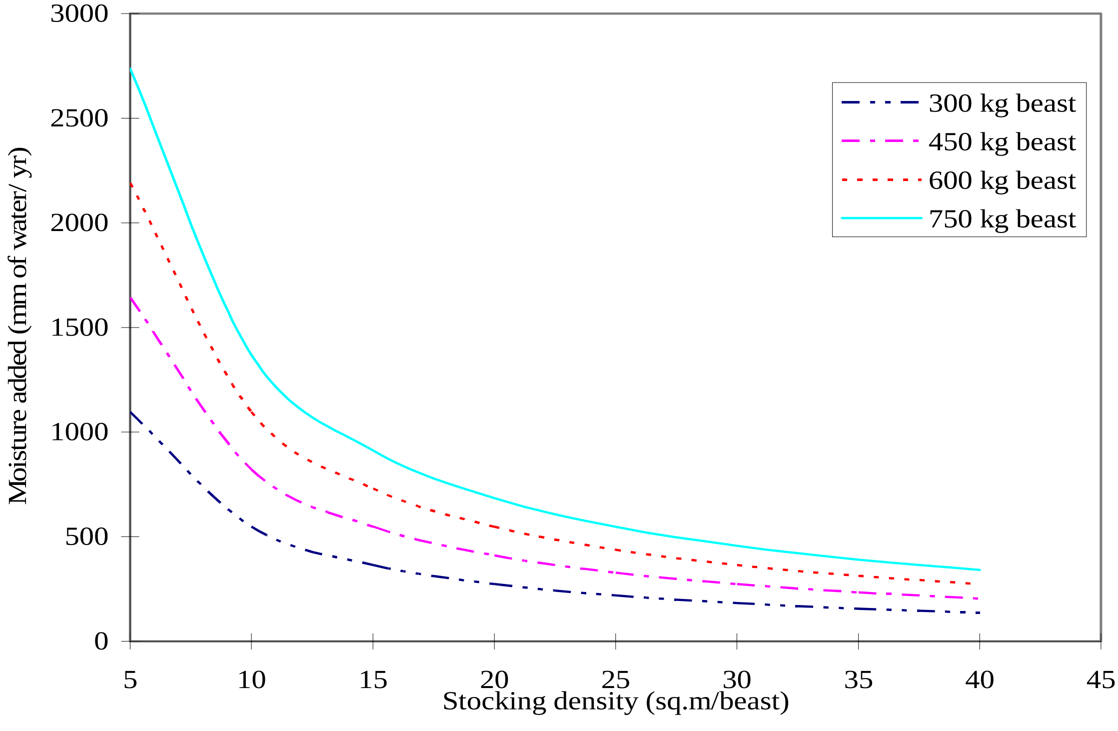


Figure 8. Water Added to a Pen Surface in Urine and Faeces.

Research by the Cooperative Research Centre for the Beef and Cattle Industry (Beef CRC) has proven the data on manure accumulation previously used, is incorrect. Manure accumulation does not increase linearly with beast weight. This is because the metabolism of the animal peaks at a weight of about 550 kg, plateaus and then slows as the animal has reach maturity and subsequently does not consume the amount of feed and water it needs to sustain rapid growth. In part this has been know for a number of years because feed consumed by larger stock is reflected in the weight of rations fed for which industry has substantive data.

The Effect of Stocking Density

There is some confusion between the use of a Standard Cattle Unit's and the use of a beast weight for determination of a feedlot's capacity. A Standard Cattle Unit is equivalent to a animal weighing 550 kg. In Queensland, however, the capacity of a feedlot is determined as a function of animals weighing 600 kg. In NSW the EPA utilises the Queensland guidelines, but regulates the feedlot on the tonnes of production. Because manure production generally peaks in the weight range of 550-600 kg little or no difference in feedlot capacity or stocking rates at a SCU and higher weight is likely. None the less it is best for uniformity to quote stocking densities as an area (m^2) per SCU.

Manure Accumulation Rates

Cattle stocked in pens at different densities will influence the rate of manure accumulation and the amount of water added to the pen surface. Lott (1998) details the rate of manure accumulation on a pen surface at about 0.6mm/day of dry compact manure. Further data on pen accumulation rates have been collected and described by Petrov *et al*., (2000). These data (0.2-0.5 mm/day) corroborate the findings of Lott (1998) given differences in stock rates and beast weights. It is possible to calculate the manure accumulation rates based on the amount of feed supplied to stock in pens. The manure accumulation rates have been calculated for four different classes of animals.

Table 1. Manure accumulation rates (data in Table 1 match those presented in the literature (Lott, 1998; Petrov *et al.*, 2001) These data show that in feedlots stocked with animals destined for the long fed Japanese market at a rate of about 15 m^2/head the manure accumulation rates is about 0.5 mm/day (dry compacted manure). Over an eight-week period this equates to a maximum dry manure accumulation of about 40 mm)

	Stocking Density (m2/h)	Trade Steer	Short-fed Steer	Mid Fed Steer	Long-fed Steer
Days on feed		70	105	150	250
Average daily gain (kg/day)		1.5	1.6	1.4	1.2
Entry weight (kg)		350	440	440	400
Exit weight (kg)		455	608	650	700
Average weight (kg)		402.5	524	545	550
Average daily DM intake as a % of weight		2.1	2	1.9	1.8
Ration consumed (wet kg)		8.5	10.5	10.4	9.9
MC of ration (%)		0.3	0.3	0.3	0.3
Ration consumed (dry kg)		5.92	7.34	7.25	6.93
MC of manure profile in pen (5)		0.3	0.3	0.3	0.3
Bulk density - manure profile (kg/m^3)		900	900	900	900
Rate of manure accumulation (mm/day)	10	0.66	0.82	0.81	0.77
	12.5	0.53	0.65	0.64	0.62
	15	0.44	0.54	0.54	0.51
	17.5	0.38	0.47	0.46	0.44
	20	0.33	0.41	0.40	0.39
Weeks to reach 50 mm	10	10.9	8.8	8.9	9.3
	12.5	13.6	11.0	11.1	11.6
	15	16.3	13.1	13.3	13.9
	17.5	19.0	15.3	15.5	16.2
	20	21.7	17.5	17.7	18.6

Pen Cleaning Frequency

The current Queensland guidelines stipulate maximum manure depths and pen cleaning frequencies for each Class of feedlot and allowable stocking densities. These guidelines have been adopted by the NSW EPA. The guidelines state that the maximum allowable depth of manure for a Class 1 feedlot with a stocking density of 15m^2/SCU is 50 mm of manure. This is the depth of manure above the interface layer which in most cases should be maintained on the pen surface to limit movement of water inter the near soil surface. The interface layer is generally 20-50 mm in depth. The data in Table 1 provides more accurate pen cleaning frequencies for different classes of stock given the 50 mm depth of manure accumulation allowed for Class 1 operations.

Deep Manure and Stock Performance

Wet muddy conditions affect animal welfare. Animals may suffer an increased incidence of health problems and be less comfortable in pens containing wet manure. For instance, the incidence of foot problems, such as footrot, increases with wet muddy conditions. Wet conditions also pose difficult conditions for pen riders. The presence of deep manure in a pen has a detrimental effect on daily gains and feed conversion efficiency. Deep manure and mud (20-30 cm) could reduce daily gains by 25 to 37% and the feed conversion efficiency by 20 to 33% (Bond *et al.*, 1970).

Dust Management

Dust control can be achieved by either cleaning dry powdery manure off the pen surface or sprinkling the pens with water. When loose manure is removed stock movement will scuff compacted manure from the pen profile re-establishing the layer of loose manure. If the generation of loose manure and its subsequent remove occurred over an extended dry period then the manure profile can be reduced to the extent that the manure pack is destroyed. On the other hand wetting manure to minimise dust is fraught with potential problems. For example over wetting the manure will result in boggy conditions and increased odour, in pen humidity and ammonia production.

APPENDIX D – COOLING CATTLE BY WETTING

COOLING CATTLE BY WETTING

Mr Glen Gordon[1] and Dr Simon Lott[2]

1 Agricultural Engineer, E.A. Systems
2 Principal Environmental Engineer, E.A. Systems

Key Recommendations

- A Sprinkler Cooling System is generally considered to be an economical and practical way to cool cattle under conditions of excessive heat load, aside from shade.
- Spray cool cattle when ambient temperatures exceed 35°C and in conditions when the relative humidity is less than 60% (T_w = 28°C).
- The temperature of water used for spray cooling should be 25°C or less.
- In the wetting phase of spray cooling, thoroughly wet the cattle's hair layer to the skin.
- Spray cooling can have significant negative impacts which need to be carefully managed by metering application rates.

Introduction

Cattle need to be consistently gaining weight for a feedlot to be profitable. Any factors that reduce or inhibit weight gain need to be addressed and heat stress is one of these factors. The effects of heat stress have a significant negative effect on beef production. When cattle become heat stressed they have a reduced feed consumption, which in turn reduces their performance. The heat stress threshold temperature for cattle is 25°C. When the ambient temperatures rise above 25°C, the symptoms of heat stress start to become evident, through visible metabolic changes (eg. panting) may not be seen until higher temperatures are reached.

Alleviating heat stress in cattle can be achieved by reducing the heat load (shade) or by dissipating heat from the animal to lower its body temperature (spray cooling). If the incoming solar radiation is 39MJ per day, shade reduces this heat load by 70%, or by 27MJ. It is still possible to have heat stressed cattle with shade. This is where spray cooling is important. Spray cooling dissipates a further 15MJ of energy from the system per application (Where ambient air temperature 35°C, water temperature is 25°C and relative humidity is less than 60%).

The ambient air temperature at which heat stress starts in *Bos taurus* cattle is 25°C, so the water applied should not exceed this value. To maximise efficiency and save cooling costs, water-cooling needs to be minimised. The temperature of the applied cooling water should be 25°C or less.

As the ambient air temperature approaches body temperature the cattle's natural cooling mechanisms (such as sweating) are significantly reduced. When ambient temperature exceeds the body temperature the cattle start gaining heat from their surrounds, rather than dissipating heat. While drinking cool water increases heat loss from the animal, when temperatures exceed 35°C much greater heat loss mechanisms are needed to keep cattle comfortable.

Current Practices and Technologies to Spray Cool Cattle

There are two key cooling systems that are used in cattle industries. These are described below.

Misters - Disperse a fine water droplet at a relatively lower temperature than the air, which evaporates, cooling the air. The air then cools the cattle. Mist systems are only successfully when used in conjunction with fans or in windy conditions and when there is an evaporative demand. The mist droplets are too large to be evaporated before reaching the ground. If the mist only wets the outside of the fur and not into the hide, an insulating layer of air can be trapped between the hide and the mist on the outside of the fur (see Figure 11 below). This will reduce evaporative cooling (by sweating) from the animal. This cooling method also increases the ambient air's relative humidity, which can increase heat stress (if evaporative demand is suppressed), ammonia production and odour.

Sprinkler Systems - Disperse large water droplets to wet the hair coat to the skin (see Figure 1 below). Cooling occurs when the body heat is transferred to the evaporating water (sensible and latent heat transfer drives evaporative cooling). Convective cooling which increases with air velocity enhances this process. If more water is applied than what can be captured by the hide and hair, this excess water will run-off the animal onto the ground. Evaporation from wet pen manure will increase the relative humidity and ammonia production that decreases the ability of the atmosphere to evaporate water. Therefore, excessive applications in feedlot pens can be counter productive. If there are significant amounts of excess water it could have environmental impacts with regard to odour and wastewater generation. To minimise these problems the sprinklers can be operated intermittently, so the sprinklers operate for long enough to wet to the hide, then shut-off till the hide is dry again. It is generally recommended not to apply more than 3-5mm per day for the purpose of cooling cattle. Beyond this the pens become wet.

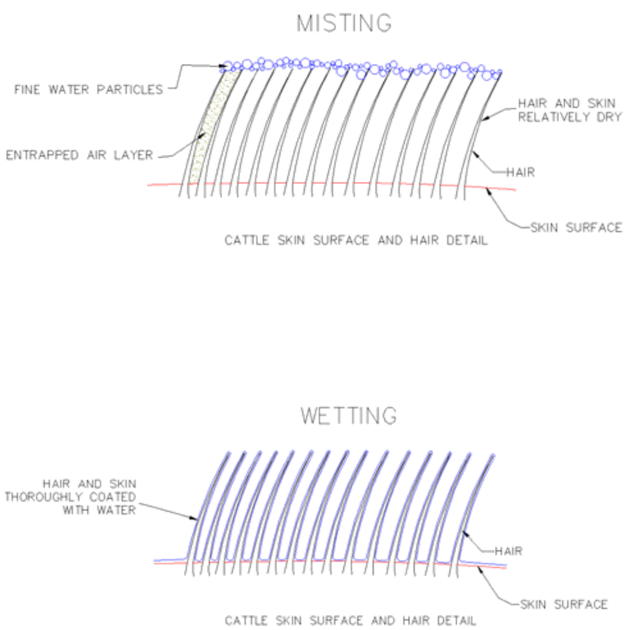


Figure 1. Effects of droplet size on wetting.

A sprinkler cooling system is generally considered to be the most economical and practical way to cool dairy cows. This is dependent upon multiple spray applications which generally aren't possible in feedlots. In dairies the system is significantly enhanced when used in conjunction with fans to increase convective cooling. In feedlots, siting and passive means of promoting air movement must be used. The alternative to these cooling methods are dietary manipulation and providing shade. In times of heat stress reduced feed intake is an effective and natural method of controlling body temperature. The reduced intake lowers the excess heat produced, also lowering the weight gain. Dietary manipulation (reduced grain content) is also a key means of reducing heat load in feedlot cattle. Providing shade reduces the incoming solar radiation heat load on the cattle.

System Design

The design combinations of cooling systems can vary infinitely, so the following sprinkler system that is outlined is what are most commonly used in dairies. It is a fully automated and fixed system.

The system generally includes;

- Controller (timer) and thermostat
- 180^o and/or 360^o sprinklers
- Pressure regulator
- In-line filter
- Pressure gauge
- Pipe, connections and fittings, valves etc.

In diary cooling systems sprinklers are set-up above the cattle, typically from the roof at a height range of 2.4 to 4 m. Low pressure systems are preferred (~10 psi) to achieve a large droplet as it better penetrates the hair layer wetting the cattle through the hair to the skin. The recommended application time for diary cows is about 0.5 to 3 minutes, allowing the water to soak into the hair through to the skin. Each application the volume of water applied typically ranges from 2-6 mm. It is suggested the applications be cycled every 30-60 minutes approximately, but may need to be adjusted depending on the prevailing conditions. The systems ideally have a Thermostat Control for activation once the temperatures reach over a preset value. A suitable temperature for system activation within Australia is 35^{o}C (ambient air temperature). A concrete pen floor is required.

There are several physical factors, which limit the system including adequate water supply, size of wastewater system and infrastructure. This system uses a lot of infrastructure and generally requires a lot of extra capital works in this infrastructure. Such systems are not readily applied to feedlots.

In feedlots the sprinklers need to be carefully positioned so they don’t wet the feed, but maximise the number of cattle being suitably wetted. The amount of ground wetted needs to be minimised. The sprinklers, in all cases, should be set-up in areas where cattle accumulate in times of hot weather, such as the back of pens. The sprinklers should be operated between feeding periods and when cattle aren’t congregated under shade (ie late afternoon). There needs to be good drainage on the wetted area to prevent the development wet boggy areas. The pen floor beneath shades may need to be reinforced (concrete stabilised road base) to prevent damage by cattle when manure becomes overly wet.

The pen area versus cattle density needs to be considered. If the density is low, water is wasted and the costs per animal increase. However if the density is high airflow is inhibited, increasing relative humidity generating a less efficient atmosphere for evaporative cooling.

A sprinkler system can use an appreciable amount of water when cooling a herd. To effective cool cattle about 4 mm of water needs to be applied into the hide. Assuming; 5 mm of water was applied (allowing for 20% of applied water to drain off the hide), a stocking density of the feedlot is $15m^2$ per animal; then 75L per animal would be applied per application. For a 20 000 head feedlot this would require 1.5 ML of water for each application. This system also requires a properly sloping pen floor to handle the increased drainage requirement. The holding pond must include this drainage in its design.

Impacts of Spray Cooling Cattle

Spray cooling can have significant negative impacts on the pen microclimate and feedlot environment if construction and management isn't appropriate for the given circumstances. Careful management of a spray cooling system is vital if its benefits are to out-weigh the possible impacts. The system needs to be operated according to the prevailing conditions. The amount of time the sprinklers operate and the time allowed for drying significantly affects the performance of the system. To maximise the cooling of the system, these timings need to be optimised.

Spray cooling adds water into the pen environment, increasing relative humidity. In times of low wind speed (which can occur at times of excessive heat) this local increase in relative humidity becomes significant and will actually cause additional heat loading of livestock by reducing the efficiency of loss mechanisms (sweating etc.).

When the pen surface becomes wet, this leads to greater odour and ammonia production. The increase in ammonia further increases the stress in the cattle. All these impacts are increased if the spray cooling occurs under shade where wet manure conditions are promoted. This increase in relative humidity can be reduced by increasing airflow and increased drying to remove the excess moisture.

While spray cooling has some negative impacts, there are some other beneficial effects. Excess water applied to the cattle will also help with dust control. A dust control system and the spray cooling system might even be able to be combined into a single system. Spray cooling in the late afternoon would occur when dust control is most needed. Another benefit of wetting the ground at this time is that it reduces the pen surface temperature before nightfall. Wetting should never cause the pen manure to become wet as wet black manure heats by massive solar radiation adsorption and microbial activity.

APPENDIX E – KEEPING DRINKING WATER COOL

KEEPING DRINKING WATER COOL

Mr Glen Gordon[1] and Dr Simon Lott[2]

1 Agricultural Engineer, E.A. Systems
2 Principal Environmental Engineer, E.A. Systems

Key Recommendations

- Drinking water should be supplied at about 16-18^{o}C and not above 25^{o}C.
- Evaporative cooling ponds have the most potential as a cooling system for providing cool drinking water to feed-lot cattle
- Modify trough design and practice measures to reduce heating at troughs.
- Bury pipeline 600mm under the ground.

Background

The energy balance of a steer (see Figure 1 below) is directly influenced by surplus energy derived from digestion of ingested feed, adsorption of radiation, convective losses, evaporative cooling and the temperature of ingested water. The amount of energy required to heat water to body temperature varies as a function of the amount of water drunk and the temperature of the water. When cattle become heat stressed they have a reduced feed consumption, which in turn reduces their performance. The feed intake of cattle is dependent on water intake, which is a function of water temperature. The energy reduction achieved by supply cool water to heat stressed animals is comparatively small, but pivotal.

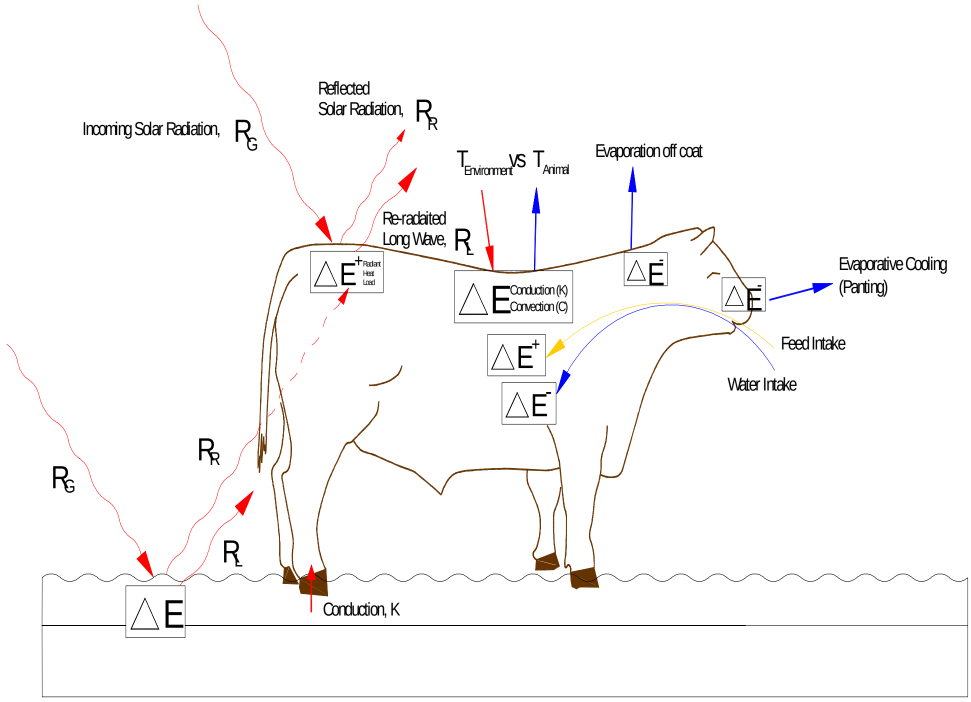


Figure 1. Energy Balance of a Feedlot Steer.

It is possible calculate the energy balance of a steer using equations obtained by research and experimental data. Table 1 contains the energy inputs and outputs to a steer for a day given different conditions. These data are empirical and can only be considered approximate. They show that under hot (35oC) and still conditions and no shade the animal accumulates energy that would lead to excessive heat loads and thus stress. No account for the effects of humidity has been included.

Table 1. Calculated energy transfer under difference climatic scenarios

	Cold and Windy		Cold and Still		Hot and Windy		Hot and Still	
	Shaded	Unshaded	Shaded	Unshaded	Shaded	Unshaded	Shaded	Unshaded
Metabolic heat production	+104 MJ	+104 MJ	+104 MJ	+104 MJ	+104 MJ	+104 MJ	+104 MJ	+104 MJ
Incoming radiation	+10 MJ	+39 MJ	+10 MJ	+39 MJ	+10 MJ	+39 MJ	+10 MJ	+39 MJ
Radiant heat loss	-141 MJ	-141 MJ	-141 MJ	-141 MJ	-22 MJ	-22 MJ	-22 MJ	-22 MJ
Water consumption	-6.0 MJ	-6.0 MJ	-6.0 MJ	-6.0 MJ	-3.5 MJ	-3.5 MJ	-3.5 MJ	-3.5 MJ
Convective loss	-360 MJ	-360 MJ	-104 MJ	-104 MJ	-138 MJ	-138 MJ	-103 MJ	-103 MJ
Net energy change	-393 MJ	-364 MJ	-137 MJ	-108 MJ	-49.5 MJ	-20.5 MJ	-14.5 MJ	+14.5 MJ

An animal must expend energy increasing water it consumes to body temperature. When an animal drinks 50 L of water at 10^{o}C about 6 MJ of water is transferred from the animal to the cool water. Clearly, supplying cool water for drinking has a limited but important direct cooling effect. The other benefits associated with drinking cooler water have a significant impact in reducing heat stress, making it a very worthwhile practice. This includes; increased water uptake, improves feed conversion, reduces illness, improves cooling ability and improves body functions. It also maximises their cooling ability through sweating, breathing and decreasing body temperature. It is recommended that water be supplied ideally at 16-18^{o}C, but below 25^{o}C.

Whether supplying drinking water or spray cooling cattle, the water temperature is critical and needs to be maintained below 25^{o}C. Often the water supply temperature is above 25^{o}C and needs to be cooled. There is a range of commercially available technologies to either cool water, maintain cool water temperatures, or prevent heating of water.

Commercially Available Technology on Water Cooling

There are several commercially available technology systems to either; cool water, maintain cool water temperatures, or prevent heating of water.

a) Heat Exchanger

A heat exchanger (see Figure 2 below) uses systems that transfer heat from one substance to another, typically liquid to liquid. Heat exchangers are widely used for commercial and industrial applications when cooling to low temperatures are required, also when cooling significant temperature ranges. Typically these systems are more expensive both in capital expenditure, operational costs and on-going maintenance. Feedlot applications would require a large commercially available system, which would be very expensive.

When cooling water for feedlot applications, the head loss of these systems (friction of water in the reticulation system) can become relative high and needs to be considered, particularly in the case of medium to high flows. Water quality can be a significant issue with these systems. Corrosive waters and solid particles can cause the system to wear quickly increasing costs. While heat exchanges transfer heat efficiently, it requires a cooler liquid to transfer the heat to.

In feedlot applications finding enough cool liquid for the system to operate will often be the limiting factor. These systems are more suited to cooling lower flows by a greater temperature using a refrigerated liquid. A large system would be required to cool 15 l/s (1.3ML/day or approximately 25 000hd @ 50L/day) by 10^{o}C. This system would be most suited to only the smaller feedlots with a very hot bore, requiring a large cooling requirement.

Figure 2. The Common Types of Heat Exchangers are Coil, Plate and Shell-and-Tube.

b) ***Cooling Tower***

A cooling tower, as shown in Figure 3 below, exchanges heat from warm water to cool dry air. This is achieved by spraying water in a rain like pattern through the air, so they come in direct contact with each other and allow the transfer of heat. The cooling mechanism is from convective heat transfer of the water, through evaporation. The heat dissipated increases the air temperature and evaporates the some of the water, but cooling the remainder. This system is widely used in commercial and industrial processes for cooling very large flows (<1400 l/s), a relative small amount (5-15^{o}C). Some applications are in power stations and very large evaporative air conditioners. This system is generally considered to be an effective method of cooling large amounts of water.

Figure 3. Induced Draft and Forced Draft Cooling Tower.

This system is possibly the next best alternative to the evaporative cooling pond. This system performance will be limited in areas of high humidity. Another limiting factor is this systems performance is dependent on the prevailing environmental conditions. Water quality needs to be continually monitored and treated when required. As a result this system would require to be licensed.

The capital cost of this system is high. The typical types and sizes of cooling towers that would be used in these situations can be seen in Figure 3 above. These units are prefabricated and transported onsite. These prefabricated units cost approximately $20,000, which doesn’t include site works, connections (electrical and water) or transport from factory.

c) Evaporative Pond Cooling

A method to cool water is to use a large storage (several days water supply) and let it evaporative cool into the atmosphere. The heat is dissipated through evaporating the water from the storage surface. This would create a temperature gradient in the water profile, with the cool water on the bottom. This would allow further cooling at night, where heat would radiate from the warmer water to the cooler atmosphere. A water supply could then be drawn from the bottom of the pond where it is coolest.

Figure 4. Evaporative Cooling Pond.

Evaporative cooling ponds could be a very effective, yet cheap method of cooling. It requires minimal capital cost and very low operating and maintenance costs. The management of this system is very low. While this system has enormous potential benefit for the beef industry it needs further basic research to determine operating constraints. Things that need to be determined are: temperature gradient versus depth of storage, influencing factors of temperature gradient, possible heat loss, potential cool water temperature, storage volumes and depths required and possible problems. Other things that could be considered are the options of enhancing this system, by shading or covering the pond.

Water quality issues may arise due to the unlined nature of these storages, allowing dirty water and aquatic vegetation into the system. This system is suited to most applications, handling large flows and high cooling requirements. A typical evaporative cooling pond that would be used in these situations can be seen in Figure 4 above. The construction of the earth storages costs approximately $10,000 for a 2.5 ML storage.

d) Cooling Grid (Pipe network/radiator immersed in water)

A cooling grid uses a water storage, typically a ring tank or dam, as the cooling medium. The water that is being cooled is passed through a pipe network immersed at depth in this water storage. Cooler water at depth is generated by heat being dissipated from the water surface through evaporation. A temperature gradient forms with the cooler water at the bottom, where the pipe network is located. These earth storages are constructed and pipe network assembled inside. The ponds are then are filled with water.

The materials used are very important because of the corrosive environment in the pond. The pipe is generally copper due to its inert properties, but galvanised and painted steel pipe have been used. The systems cooling ability is limited by the water temperature of the pond which is influenced by its evaporative cooling ability (see Section C above). This system is more suited to low to medium flows with a medium to high cooling requirement. This system has potential if a closed system is required (where the water supply stays enclosed within the pipe network, not coming into direct contact with the dam water). If a closed system weren't required the evaporative cooling pond is more likely to be more economical.

Figure 5. Cooling Grid Pipe Network.

This method of cooling is widely used in Western Queensland for town and stock water supplies for cooling water from bores drawing hot water from the Great Artesian Basin. A typical cooling grid pipe network that would be used for supplying 1.5 ML/day or 30 000head @ 50 L/day, in these situations can be seen in Figure 5 above. The earthworks cost approximately $10,000 and the pipe network cost is approximately $15,000.

e) Refrigeration System

Refrigerative coolers operate using a compressor, being driven by electricity or a motor. The environmental operating conditions of refrigerative systems are larger than all the other systems mentioned, as they are not directly affected by the weather conditions. They have the greatest ability to cool a large temperature range (>60^{o}C), but are more suited to lower flows. This system has a high energy requirement (electricity), along with expensive capital and maintenance costs. They also require specialist equipment and technicians to set up and maintain. These systems are very effective but are not always the most efficient.

This system would require a large commercially available system costing in excess of $50 000. The cost versus the benefit is prohibitive for both capital and maintenance costs.

f) Water Trough Design and Practices Measures

There are some trough design and practice measures which could reduce thermal loading on the system. The trough design and practices include; increasing trough turnover to minimise heating of the trough water, covering the troughs to reduce incoming solar radiation heating the trough, water reticulation through troughs, and/or maximise atmospheric cooling at night by increasing trough size, and selection of trough materials to reduce the sheer thermal mass of the trough.

Pipe temperature maintenance is also important in suppling cool water efficiently. If a pipeline is on or above the soil surface it gains a huge heat loading from solar radiation, the atmosphere and hot surface soils. The heat gained by the water within the delivery system needs to be minimised. Burying pipes, selecting pipe materials and insulation existing pipes can achieve this. It is recommended to bury pipes 600mm below the ground.

Conclusion

Evaporative cooling ponds have the most potential as a cooling system for providing cool drinking water to feed-lot cattle, as it is the most cost effective and efficient cooling system. There needs to be further basic research to determine operating constraints and quantify temperatures and possible heat dissipation. This system also can act as a water supply balancing storage, with a cooling capacity enhanced by shading. Most feedlots would already have a water storage that could be used as an evaporative cooling pond.

While the supply water temperature needs to be lowered where possible, there are some trough design and practice measures that could be adopted to help reduce the heating of water. These include pipe temperature maintenance and water trough design.