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Prepared by: RJ Davis and PJ Watts
FSA Consulting

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Environmental Sustainability Assessment of the Australian Feedlot Industry

Part A Report: Water Usage at Australian Feedlots

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Abstract

The Australian red meat industry, as with most primary industries, is coming under increasing pressure from both the community and government to document and justify its impacts on the environment. This project addresses the public misconceptions about the environmental sustainability of the feedlot industry by identifying and quantifying the water used in producing one kilogram of grained beef.

Water is both the most important nutrient for cattle and the most valuable natural resource (after land) in Australia. Hence, it is of critical importance to lot feeders. There is a perception in the popular press that red meat production requires large quantities of fresh water. For example, it is often stated that it takes 50,000 L of water to produce 1 kg of beef. However, in Australia, there are few facts to back up these claims. This report provides factual information on the quantity of water required to produce red meat within the feedlot sector only.

Executive Summary

The Australian red meat industry, as with most primary industries, is coming under increasing pressure from both the community and government to document and justify its impacts on the environment. Currently, a lack of credible supply chain data prevents the industry from being able to respond in a meaningful manner.

Meat and Livestock Australia (MLA) is undertaking a project (COMP.094) that will address these issues and provide credible data on the industry's environmental impacts and sustainability for use by industry, including its interactions with government, community groups and the media. This project will use the standardised tool, Life Cycle Analysis (LCA), to quantify natural resource consumption and environmental interventions to water, soil and air.

LCA is a form of cradle-to-grave system analysis developed for use in manufacturing and processing industries to assess the environmental impacts of products, processes and activities by quantifying their environmental effects throughout their entire life cycles. An LCA is essentially a quantitative study. Sometimes environmental impacts cannot be quantified because of a lack of data or inadequate impact assessment models. Quantitative analysis requires standardised databases of main processes (e.g. energy, transport) and software for managing the study's complexity.

As part of the overall industry project, the beef cattle lotfeeding sector is undertaking a related MLA project (FLOT.328) that will contribute to the whole of industry dataset, but more importantly addresses the public misconceptions concerning the environmental sustainability of the feedlot industry. It will identify and quantify the environmental costs associated with the production of one kilogram of grained beef to enable comparison with its domestic competing products (grass fed beef, lamb, pig and poultry meats). This report has been prepared as part of FLOT.328. This report covers the issue of clean water usage by cattle feedlots. It provides factual information on the volume of clean water used at Australian cattle feedlots under a range of climatic, size and management conditions.

Factual information data on water use was obtained via a detailed on-line survey of feedlot inputs and outputs including cattle numbers, intake and sale weights, dressing percentages. Annual water usage was estimated on the basis of one kilogram of dressed hot standard carcass weight gain (kg HSCW gain). In this context, HSCW gain is the difference between total dressed carcass weights of cattle leaving the feedlot less the estimated total dressed carcass weight of cattle entering the feedlot.

Little work has been undertaken to evaluate total water consumption by feedlots. The amount of drinking water used at feedlots has been studied in North America in the 1980's. To date, only a limited amount of research into drinking water requirements has been undertaken in Australia. Water is both the most important nutrient for cattle and the most valuable natural resource (after land) in Australia. Hence, it is of critical importance to lot feeders.

Results show that total annual water use ranges from 34 L/kg hot standard carcass weight (HSCW) gain to 381 L/kg HSCW gain with a median value of 73 L/kg HSCW gain over the nine feedlots studied.

The main influence on the total annual water use is the quantity of water used for dilution of effluent for irrigation. In feedlots with a capacity or need for using clean water for irrigation, a substantial increase in annual water use per kg/ HSCW gain was found. Variation between feedlots may be explained by management operations including frequency of trough cleaning, cattle washing, dust control and feed processing.

Whilst, total annual clean water records by lot feeders are usually good, little data exists on actual usage levels in individual components viz drinking water, feed processing, cattle washing. More information is required on the water usage of individual components before these figures can be reliably reported.

The outcomes of this study will allow the feedlot industry to develop a better understanding of the total annual water usage relativity and contributions that various feedlot sector operations have on annual clean water usage. This information is invaluable for future design and management considerations.

The data presented in this report was used as inputs into the life cycle inventory for the clean water use component of the feedlot sub-system.

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1 Background

The Australian red meat industry, as with most primary industries, is coming under increasing pressure from both the community and government to document and justify its impacts on the environment and its use of natural resources. This is evident through the government emphasis on industry initiatives such as the implementation of Environmental Management Systems (EMS) and Triple Bottom Line (TBL) reporting requirements. Currently, a lack of credible supply chain data prevents the industry from being able to respond in a meaningful manner.

Meat and Livestock Australia (MLA) is undertaking a project (COMP.094) that will address these issues and provide credible data on the industry's environmental impacts and sustainability for use by industry, including its interactions with government, community groups and the media. This project will utilise the standardised tool, Life Cycle Assessment (LCA), to quantify natural resource consumption and environmental interventions to water, soil and air.

A separate but related project (FLOT.328) is being undertaken for the lot-feeding sector of the Australian red meat industry.

1.1 FLOT.328 Project Description

As part of the overall industry project, the beef cattle lot feeding sector is undertaking a related project (FLOT.328) that will contribute to the whole of industry dataset, but more importantly will address the public misconceptions of the environmental sustainability of the feedlot industry by identifying and quantifying the environmental costs associated with the production of one kilogram of grained beef to enable comparison with its domestic competing products (grass fed beef, lamb, pig and poultry meats).

Given that environmental sustainability will eventually become a key element in maintaining and improving access for Australian product into key overseas markets, it is envisaged that the project will also benchmark these costs against international competitors (US and European beef) and identify areas of R&D investment to ensure the long-term viability and sustainability of the feedlot production system.

2 Project Objectives

The FLOT.328 project will:

1. Collect, collate and present relevant data to enable MLA to assess/benchmark the environmental sustainability of the feedlot industry against its domestic and international competitors by assessing the environmental costs associated with the production of one kilogram of meat from each production system
2. Provide data for the feedlot industry suitable for use within the broader red meat supply chain Life Cycle Assessment (COMP.094)
3. Identify areas for potential future R&D investment to ensure long-term competitiveness, viability and sustainability of the feedlot production system; and
4. Communicate the results of the assessment to MLA in a format suitable for dissemination to industry stakeholders.

This report covers the issue of the usage of one resource by feedlots – water.

Water is both the most important feed component fed to cattle and the most valuable natural resource (after land) in Australia. Hence, it is of critical importance to lot feeders. There is a perception in the popular press that red meat production requires large quantities of fresh water. For example, it is often stated (with little presentation of reference material) that it takes 50,000 L of water to produce 1 kg of beef. However, in Australia, there are few facts to back up these claims. This report aims to provide factual information on the quantity of water required to produce red meat within the feedlot sector only.

For this report, the definition of water use is that used by Foran et al. (2005).

'Managed water use denotes the consumption of self-extracted water (water from rivers, lakes and aquifers, mainly extracted by farmers for irrigation) as well as mains water, in units of litres (L). Collected rainfall, such as in livestock dams on grazing properties is not included in these figures'.

Hence, in this analysis, only water supplied from bores, rivers, irrigation channels and reticulated pipelines will be considered.

2.1 Project Reporting Structure

This project includes the collection and analysis of a large quantity of data from operational feedlots on the environmental costs associated with the production of one kilogram of hot standard carcass weight gain (HSCW). In this context, HSCW gain is the difference between total dressed carcass weights of cattle leaving the feedlot less the estimated total dressed carcass weight of cattle entering the feedlot. To ensure all this data and information is presented in a suitable manner, six reports will be compiled.

A. Water Usage at Australian Feedlots. This report presents a background literature review of water usage at feedlots, data collection and results, as well as an analysis and discussion of the data collected. This report is the life cycle inventory for the water use component of the feedlot sub-system.

B. Energy Usage and Greenhouse Gas Emission Estimation at Australian Feedlots. This report presents a background literature review of energy usage and GHG emissions at feedlots, data collection and results. A discussion of results and the relative merits of the current GHG emission calculation methodology by the Australian Greenhouse office (AGO) are included. This report is the life cycle inventory for the energy use and GHG emissions component of the feedlot sub-system.

C. Nutrient Cycling at Australian Feedlots. This report includes a literature review of nutrient pathways at feedlots, data collection and results as well as an analysis and discussion of the data collected. This report is the life cycle inventory for the nutrient cycling component of the feedlot sub-system.

D. NPI Listed Substances Emission Estimation for Australian Feedlots. This report provides a summary of the National Pollutant Inventory (NPI) reporting framework, data collection and results for category I listed substances. The report also includes a discussion of the relative merits of the current NPI emission estimation methodology, with guidance on an alternative method for use under Australian conditions.

E. Review of Lot Fed Cattle Water Consumption – MRC Project No. DAQ.079. This report provides a review of research undertaken in the early 1990’s on water consumption in feedlots. It provides a more detailed literature review on the factors influencing drinking water requirements than is provided in Part A, experimental methodology, data collected and discussion of the results and outcomes of this MRC research.

F. Resource Use and Environmental Impact Assessment for Australian Feedlots. This report provides a summary of feedlot-relevant natural resources management issues (NRM), data collection and results. A discussion of the environmental impact of the use of these resources by beef cattle feedlots is also included.

3 Life Cycle Assessment

MLA is undertaking a project (COMP.094) that will provide credible data on the red meat industry's environmental impacts and sustainability for use by industry, including its interactions with government, community groups and the media. This project will utilise the standardised tool, Life Cycle Assessment (LCA), to quantify natural resource consumption and environmental interventions to water, soil and air. This project (FLOT.328) is being undertaken for the lot-feeding sector of the Australian red meat industry. The following description of LCA is taken from Peters et al. (2005).

3.1 Description of Life Cycle Assessment

LCA is a form of cradle-to-grave systems analysis developed for use in manufacturing and processing industries to assess the environmental impacts of products, processes and activities by quantifying their environmental effects throughout the entire life cycle. LCA can be used to compare alternative products, processes or services; to compare alternative life cycles for a product or service; and to identify those parts of the life cycle where the greatest improvements can be made. An international standard has now been developed to specify the general framework, principles and requirements for conducting and reporting LCA studies (Standards Australia 1998). LCA differs from other environmental tools (e.g. risk assessment, environmental performance evaluation, environmental auditing, and environmental impact assessment) in a number of significant ways. In LCA, the environmental impact of a product or the function a product is designed to perform is assessed, the data obtained are independent of any ideology and it is much more complex than other environmental tools. As a systems analysis, it surpasses the purely local effects of a decision and indicates the overall effects.

There are four aspects of life cycle assessment (see Figure 1):

- *Goal and Scope Definition* defines the goal, functional unit and associated system to be studied.
- *Inventory Analysis* analyses all process inputs and outputs. It involves modelling unit processes in the system, considered as inputs from the environment (resources and energy) and outputs (product, emissions and waste) to the environment. Allocation of inputs and outputs needs to be clarified where processes have several functions (for example, where one production plant produces several products). In this case, different process inputs and outputs are attributed to the different goods and services produced. An extra simplification used by LCA is that processes are generally described without regard to their specific location and time of operation.
- *Impact Assessment* makes results from the inventory analysis more manageable and understandable in relation to natural environment, human health and resource availability.
- *Interpretation* involves evaluating inventory analysis and impact assessment outcomes against the study's goal.

An LCA is essentially a quantitative study. Sometimes environmental impacts cannot be quantified due to a lack of data or inadequate impact assessment models. A guide to decisions can then be qualitative use of LCA and use of other tools for supply chain analysis. Quantitative analysis requires standardised databases of main processes (energy, transport) and software for managing the study's complexity.

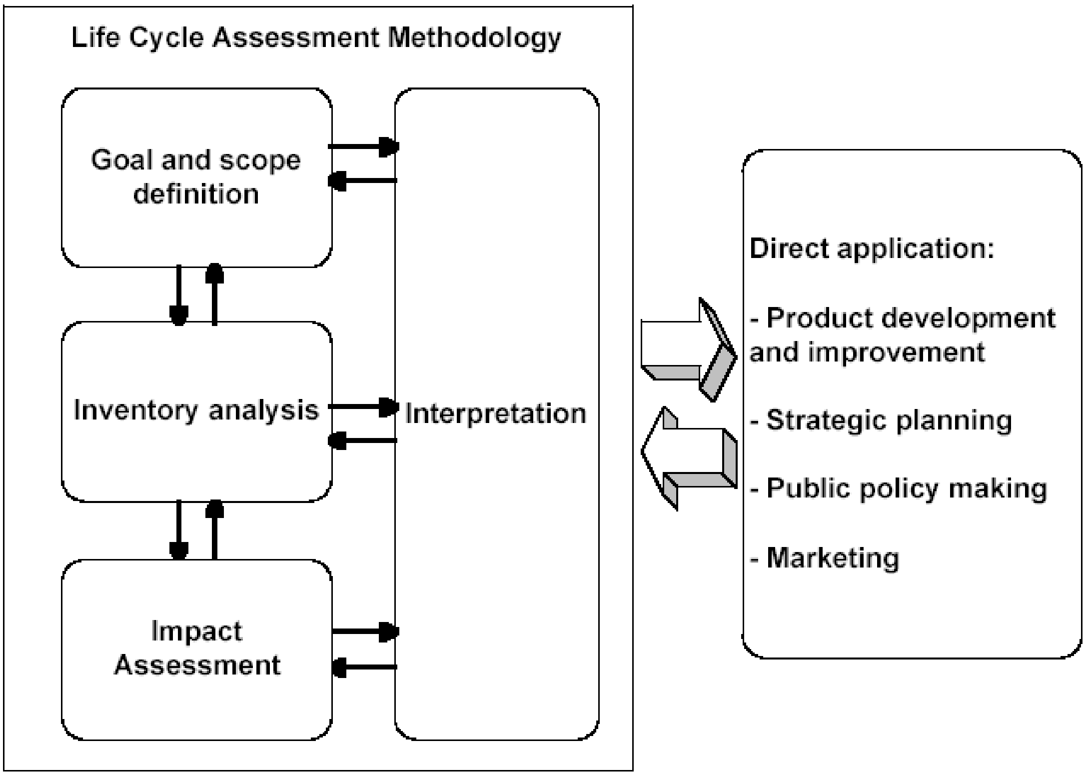


FIGURE 1 - GENERAL FRAMEWORK FOR LCA AND ITS APPLICATION (STANDARDS AUSTRALIA 1998)

3.2 Selection of Functional Unit

The functional unit for this study is the delivery of one kilogram of hot standard carcass weight (HSCW) meat at the abattoir. AUS-MEAT is the authority for uniform specifications for meat and livestock in Australia. In March 1987, they introduced the term HSCW as a national standard. The HSCW is the fundamental unit of “over the hooks” selling and is the weight, within two hours of slaughter, of a carcass with standard trim (all fats out). This is a carcass after bleeding, skinning, removal of all internal organs, minimum trimming and removal of head, feet, tail and other items (AUS-MEAT 2001). “Hot” indicates that the meat in question has not entered any chilling operations. This output-related functional unit was chosen, rather than an input-related one, in order to describe the human utility of the processes under consideration – the provision of nutrition for people. Although the meat could be served in different ways, this functional unit makes the different processes under consideration “functionally equivalent” from a dietary perspective.

3.3 System Boundaries

In LCA methodology, usually all inputs and outputs from the system are based on the ‘cradle-to-grave’ approach. This means that inputs into the system should be flows from the environment without any transformation from humans and outputs should be discarded to the environment without subsequent human transformation (Standards Australia 1998). Each system considers upstream processes with regard to the extraction of raw materials and the manufacturing of products being used in the system and it considers downstream processes as well as all final emissions to the environment. Figure 2 shows the generalised system boundary for the red-meat sector as defined for the COMP.094 project. Within this boundary, there is a sub-system for the feedlot sector. The boundary chosen here (shown in red on Figure 2) is the feedlot site itself plus the transport component of bringing cattle and feed into the feedlot and delivering cattle from the feedlot. The production of feed for the feedlot will be examined in a larger system analysis.

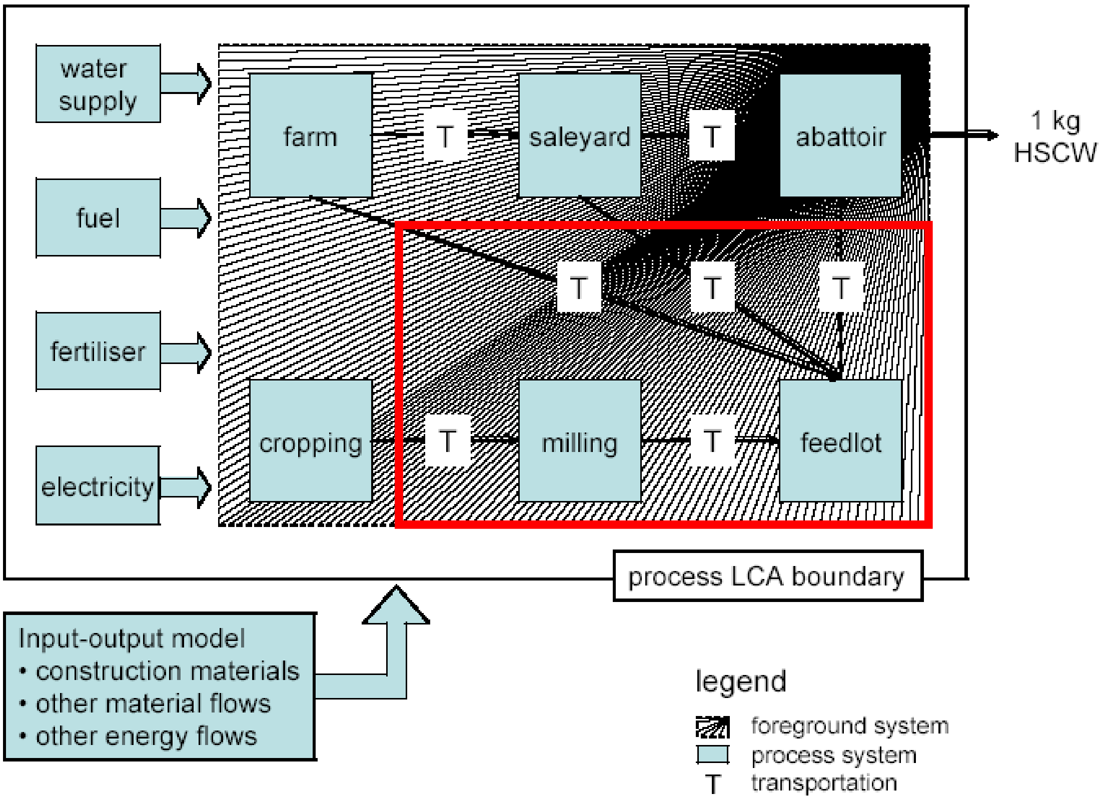


FIGURE 2 – GENERALISED SYSTEM MODEL FOR THE RED MEAT SECTOR WITH FEEDLOT SUB-SYSTEM

3.4 Life Cycle Inventory

Inventory analysis is the second phase in a life cycle assessment and is concerned with data collection and calculation procedures. The Inventory Analysis phase forms the body of the LCA as the majority of time and effort in an LCA is spent on Inventory Analysis. As a rule of thumb, 80 percent of the time required for an LCA is needed for this phase. The operational steps in preparing a life cycle inventory (LCI) are according to ISO 14041 (Standards Australia 1999):

- data collection.
- relating data to unit processes and/or functional unit.
- data aggregation.
- refining the system boundaries.

This report is the life cycle inventory for the water use component of the feedlot sub-system.

4 Literature Review

4.1 Water Requirements at Cattle Feedlots

Clean, fresh water is required or used at cattle feedlots for the following purposes.

1. Drinking water consumption by the cattle.
2. Cleaning of water troughs, evaporation and other losses from water troughs and pipes.
3. Cattle washing (finished cattle prior to dispatch to processing works).
4. Evaporation losses from holding storages.
5. Feed preparation.
6. Staff amenities, and
7. Supplementation of effluent irrigation.

4.2 Drinking Water Consumption by Cattle

Water is the most vital single requirement of livestock as they are dependent on it for survival. Water is an extremely important nutrient since it makes up about two thirds of the fat-free animal's body (Church 1979).

Water is required by feedlot cattle for regulation of body temperature, growth, digestion, metabolism, excretion, hydrolysis of proteins, fat and carbohydrates; regulation of mineral homeostasis, joint lubrication, nervous system cushioning, sound transmission and sight. Restriction of water intake immediately reduces feed intake and cattle performance (Utley, Bradley & Boling 1970).

The minimum water requirement of feedlot cattle is equal to the sum of the minimum losses in faeces and urine, evaporative and respiration losses and water used in weight gain. The actual intake of water consistently exceeds the calculated minimum requirement. Water is the only nutrient for which the requirement is based on voluntary intake (Standing Committee on Agriculture 1990).

The conceptual water balance of a 450 kg feedlot steer is shown in Figure 3. Water is taken into the animal mainly as drinking water but a little is contributed by the feed. Water leaves the animal in manure (faeces and urine), sweat and respired air.

The quantity of water consumed by feedlot cattle is mostly dependent on the environmental temperature and humidity, drinking water temperature and salt content, diet composition (nature of food and dry matter content), feed intake, size of the animal, breed, rate and composition of gain, frequency of watering and individual variation between animals (ARC 1980). A detailed review of the above factors can be found in FLOT.328 *Part E Report:* Review of Lot Fed Cattle Water Consumption – MRC Project No. DAQ.079 (Watts, Davis & Tucker 2006). A summary of environmental factors influencing water intake are presented here.

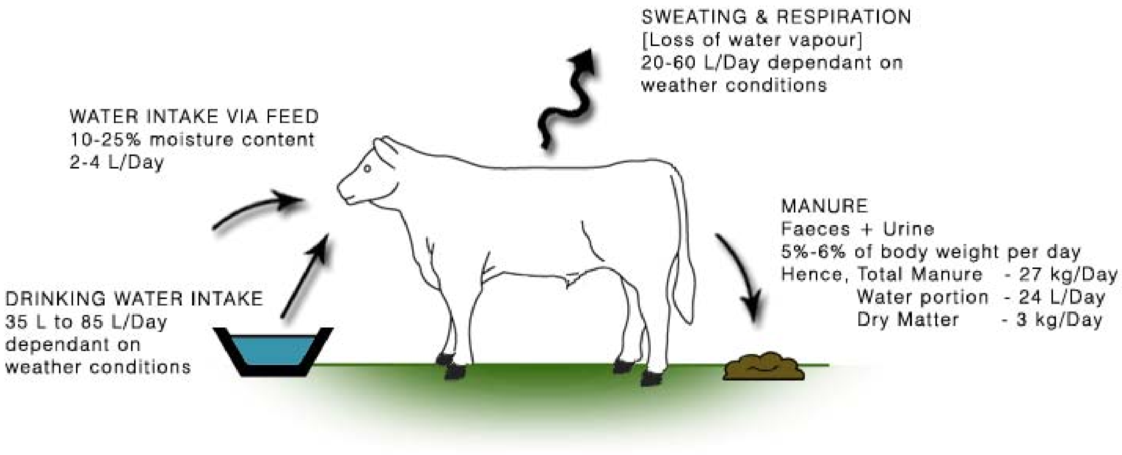


FIGURE 3 – CONCEPTUAL WATER BALANCE OF A 450 KG STEER

By way of definition, "water consumption" is 'free water' drunk by cattle while "water intake" includes both water drunk and water contained in feed. Cattle drinking at water troughs are shown in Photograph 1.

PHOTOGRAPH 1 – CATTLE DRINKING AT WATER TROUGHS

4.2.1 Environmental Factors influencing Water Intake

The animal's environment directly influences its drinking pattern, performance and even survival. Weather is usually considered a constraint on efficient livestock management, as it is unpredictable and variable. Livestock water requirements may be influenced by the exposure of cattle to thermal stress. Cattle rely on evaporative cooling to maintain their normal body temperature under varying environmental conditions. To do this, their water intake must increase.

Exposure of cattle to thermal stress leads to a number of physiological responses such as: increased sweating rate, elevated rectal temperature, increased respiration rate and/or increased pulse rate. Associated with these are declines in feed intake and dry matter intake (DMI) (a direct attempt to reduce heat production), growth, health and well being (McDowell 1972; Kabunga 1992; Hahn and Nienaber 1993; Gaughan et al. 1996). McDowell (1972) compiled the following factors for an animal, which is compensating following exposure to increasing ambient temperature:

- Change in vascular blood flow.
- Increased sweating rate.
- Increased respiration rate.
- Changes in hormone secretion or endocrine activity.
- Changes in behavioural patterns.
- Increased water intake.
- Increased body temperature.
- Change in the state of hydration.

The order in which these functions take place has not been reliably determined. It has been argued that behavioural changes take place before there is any physiological response. Robertshaw (1985) stated that the first response to increasing thermal load is behavioural. Animals firstly change posture, seek shade, wallow, and/or decrease DMI. If these are not options, then the animal will use physiological functions (e.g. blood flow, sweating, panting) to alter body temperature. Young and Hall (1993) listed behaviours which could identify cattle experiencing excessive heat load, with the onset of open-mouthed panting, laboured panting and excessive salivation/drooling suggested as indicators of an animal failing to cope and needing immediate attention to avoid collapse and possible death.

There has been a significant research effort with regard to environmental factors and heat stress in cattle (Flamenbaum et al. 1986; Hicks et al. 1988; Sparke et al. 2001; EA Systems Pty Ltd 2002; Gaughan, Goopy & Sparke 2002; EA Systems Pty Ltd 2003). With the exception of Hicks et al. (1988) most of this research has concentrated on the effects of shade, diet modification, microclimate, cooling water and the development of an index for heat stress. The effect of environmental factors on subsequent water intake has received little attention.

Environmental factors such as ambient temperature, relative humidity, wind speed, solar radiation and rain influences the animal’s final physiological state, thus determining the volume of water consumed by the beast. It is important to consider each of these factors individually. Conditions of high humidity, wind and rainfall all tend to decrease the voluntary intake of water (ARC 1980).

Ambient temperature is a measure of the intensity of heat. Cattle exposed to high ambient temperatures will inevitably become hot and need to cool themselves. Ray (1991) regards temperatures exceeding 21°C as stressful. Increasing water intake is an important method of reducing body temperature due to its involvement in the evaporative cooling process. High ambient temperatures tend to increase the consumption of water (ARC 1980). Little and Kabaija (1980) (cited in ARC 1980) found voluntary fed intake declined when water intake was restricted.

In temperate climates, water is required mainly to meet physiological needs. Species vary in their ability to tolerate dehydration and in their ability to use water to maintain a state of homeothermy (ARC 1980). Cattle seem to reduce the output of water in faeces in response to water restriction.

They do not appear to restrict output of water in urine significantly (Little & Kabaija 1980 cited in ARC 1980).

Relative humidity is the ratio of the quantity of water vapour present in the air relative to the amount of water in saturated air. The potential for evaporative heat loss is influenced by the difference between the water vapour pressure at the skin surface temperature and the actual vapour pressure of the ambient air. As the humidity of the air increases, the ability to lose heat by evaporation is reduced, becoming zero at a relative humidity of 100%. Evaporation is possible in saturated air providing the membrane of the respiratory passage has a higher temperature and therefore a higher saturation vapour pressure than the surrounding air.

Increasing humidity associated with high temperatures reduces total water intake but cattle drink more frequently (Ragsdale et al. 1953 cited in ARC 1980). This may be partly due to the lower feed intake and the reduced vaporisation of water (ARC 1980).

Radiation from the sun, sky and surroundings contribute to the animal's heat load (EA Systems Pty Ltd 2003). An unshaded beast is exposed to:

- Direct solar radiation (visible and short infrared waves) from the sun. The coat reflects a proportion of this radiation and the remainder is absorbed.
- Solar radiation reflected from the clouds and other particles in the sky.
- Solar radiation reflected from the ground and other surrounding objects (amounting to approximately 50% of the total solar radiation).

The amount of heat an animal absorbs from solar radiation is influenced by the intensity of the radiation, the animal's orientation to the sun and the absorptive reflective capacity of the animal's coat. McArthur (1987) found that radiation is directly responsible for increased skin temperature, which stimulates the secretion from the sweat glands. There are particular situations where wind can influence the heat transfer between an animal and its environment.

Rapid air movement will enhance evaporative heat loss only when the skin is moist and where air temperature is below that of skin temperature (Sparke et al. 2001). Wind may also have a heating effect if air temperature is above surface temperature and its effectiveness in heat exchange will be limited if the skin moisture supply is low. Winds of 45 m/s at temperatures of 10-26.7 ^{o}C reduced the water intake of European cattle slightly. At 35^{o}C wind velocity did not seem to have an effect with wind speeds of 1.8 m/s and 45 m/s (Brody et al. 1954 cited in ARC 1980).

Rain reduces water intake due to the associated heat loss through evaporation. Rain falls onto the animal's coat and evaporates, reducing thermal stress. The cooling effect is directly related to the depth of water penetration into the coat. Castle et al. 1972b (cited in ARC 1980) found that rainfall decreased the water intake requirements due most likely to reduced vaporisation.

Donegan, Clarke and Sivasupraunaniam (1984) proved that high humidity, poor air movement and high solar radiation all interfere with the animal's ability to dissipate heat. They concluded however that the primary cause of heat stress is high air temperatures.

There has been considerable scientific effort to develop indices that mathematically represent the physical environment (air temperature, humidity, radiation, wind speed) in terms of one or more measurable physiological or animal production responses (Sparke et al. 2001; Gaughan, Goopy & Sparke 2002).

Gaughan, Goopy and Sparke (2002) concluded that high heat load in feedlot cattle is a result of local climatic conditions (i.e. in the pen) and animal factors lead to an increase in body heat beyond the animals' normal physiological range and range and its ability to cope. By using a combination of observed local climatic conditions and animal responses to the climate (e.g. panting scores), feedlot management will be well placed to implement strategies to reduce the impact of severe hot weather conditions on their cattle.

Despite these general observations, there are very few references available in North America or Australia that allow reliable predictions of water consumption for feedlot cattle to be made.

4.2.2 Research in North America

Winchester and Morris (1956) provide data collected in a laboratory context relating water intake per day to ambient temperature, dry matter intake and breed. These data (converted to metric units) are given in Figure 4 for *Bos taurus and Bos indicus* assuming a typical DMI of 11 kg/ day. They show that water intake, and therefore metabolic demand, is relatively constant until about 30°C, above which intake increases rapidly due to increased evaporative (cooling) demand. At 38°C, Winchester and Morris (1956) measured actual water intakes of about 16 L/kg DM intake/day by *Bos taurus* breeds, and about 10 L/kg DM intake / day for *Bos indicus* breeds. Watts, Tucker and Casey (1994) undertook a statistical analysis of their data and found the following relationships between water intake and temperature.

$$\mathbf{WI = DMI \times (3.413 + 0.01592\, E^{0.17596T})}\ \textbf{- EQUATION 1}$$

for *Bos taurus* and,

$$\mathbf{WI = DMI \times (3.076 + 0.008461\, E^{0.17596T})}\ \textbf{- EQUATION 2}$$

for *Bos indicus*.

Where:

WI = water intake (litres per head per day)
DMI = dry matter intake (kg DM per head per day)
T = ambient temperature (°C).

Therefore for typical Australian summer conditions where temperatures in the order of 35°C are experienced Winchester and Morris (1956) relationship predicts a water intake of 80 L/head/day for *Bos indicus* and 120 L/head/day for *Bos taurus assuming no decline in DMI.* A small component in the order of 3 L/hd/day would result from feed intake (assuming 20% moisture content in the as-fed diet), therefore leaving water consumption component as 77 L/hd/day and 117 L/hd/day for *Bos indicus* and *Bos taurus* respectively.

Hicks et al. (1988) measured the water intake of 239 crossbred steers with an average initial weight of 330 kg over a range of conditions in a 95-day trial. As with Winchester and Morris (1956), temperature and dry matter intake were the major factors affecting water intake. They developed a statistical relationship between water intake of feedlot cattle and other variables. Their formula (converted to metric units) is:

$$\mathbf{WI = -6.1 + 0.708 \times T + 2.44 \times DMI - 0.387 \times P - 4.44 \times S} \quad \text{- EQUATION 3}$$

Where:

WI = water intake (litres per head per day)
DMI = dry matter intake (kg DM per head per day)
T = daily maximum temperature (°C)
P = daily precipitation (mm)
S = dietary salt (%)

At average temperatures (20°C) and for small cattle (< 450 kg), the formulae of Winchester and Morris (1956) and Hicks et al. (1988) produce similar results for *Bos taurus* (see Figure 4). However, at high temperatures (>35°C) and for large cattle, the two formulae produce quite different results. As Hicks et al. (1988) did not take any measurements under these conditions, the data of Winchester and Morris (1956) would be preferred for higher temperatures.

Parker et al. (2000) collected water use data from a 50,000 head feedlot in the Texas High Plains from November 1995 to October 1997. They found that the average total daily water usage was 40.9 L/hd/day.

In North America, freezing of water troughs in winter is a particular problem. To overcome this, the exposed surface area of troughs is often much smaller than in Australian feedlots (compare Photograph 2 to Photograph 3). Freezing may also be prevented by either heating the water trough or by providing a continuous flow of overflow water to prevent surface freezing. Parker et al. (2000) found that whenever water trough floats were adjusted for winter conditions 66% of total usage was for drinking, 2% was used in the feedmill and 32% was used for overflow. Whenever water trough floats were adjusted for summer conditions, 89% of water was used for drinking, 3% was used in the mill and 7% leaked into the water overflow system.

Parker et al. (2000) developed a regression equation relating water usage at the feedlot (including drinking water, feed processing - steam flaking, trough overflow) to various meteorological parameters. Their equation is:

$$\mathbf{DWU = 39.0 - 0.648 * MAXT + 0.0421 * MAXT^2 - 0.0717\ MINRH} \qquad \text{- EQUATION 4}$$

where:

DWU = daily water use (L/head/day)
MAXT = maximum daily temperature (°C)
MINRH = minimum daily relative humidity (%)

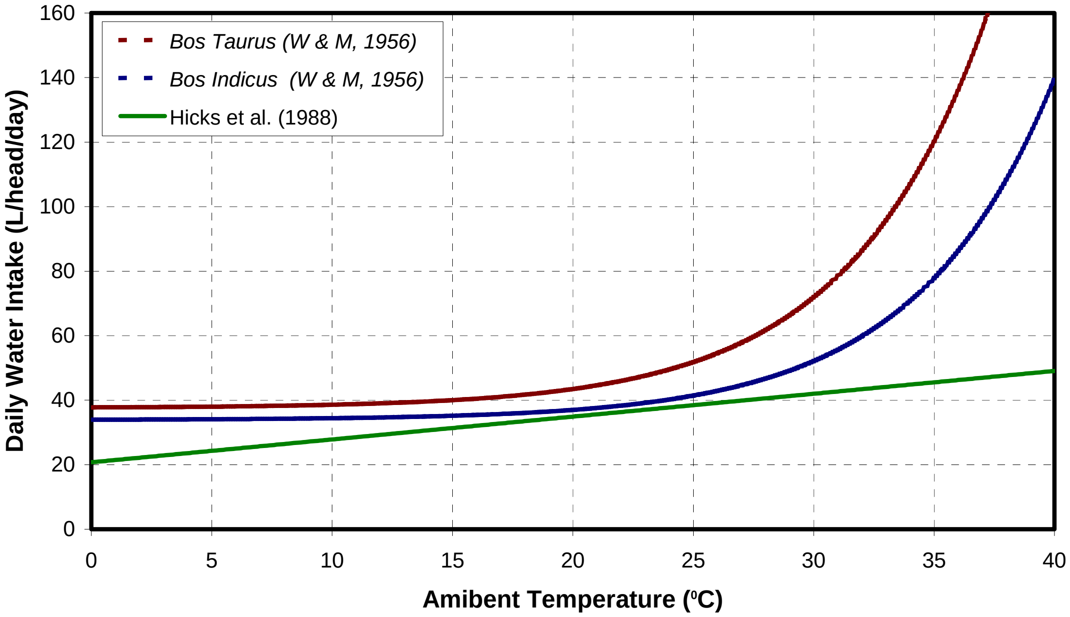


FIGURE 4 – WATER INTAKE VS AMBIENT TEMPERATURE (11 KG DMI PER DAY)

(curves adapted from Winchester and Morris (1956) and Hicks et al. (1988))

4.2.3 Research in Australia

Sanders et al. (1994) measured the water consumption of cattle at two feedlots on the Darling Downs, Queensland from November 1993 until May 1994 in an effort to understand the factors that influence the quantity and frequency of water consumption. The influence of shade and other factors on water consumption was investigated and a predictive water consumption model was formulated. This was compared to other recognised water consumption models available at the time.

Site-specific meteorological data was collected from both feedlots to allow relationships between water consumption and meteorological conditions to be evaluated. Automatic weather stations were setup with meteorological sensors for measuring air temperature, black globe temperature, relative humidity, global solar radiation, wind speed, wind direction, and rainfall. Sensors were placed in both unshaded and shaded pens.

Water consumption was monitored by water meters installed with data loggers to measure water flow into the water troughs on a 6-minute interval. For the purposes of there study, water consumption included water used for drinking, spillage and trough cleaning.

Cattle weights were recorded along with weekly data on diet type including main grain type, processing method, silage and roughage percentage, moisture content along with total consumption as-fed (kg) on shaded and unshaded pens. This allowed an average as-fed feed intake to be determined per head.

Shade in the pens was provided by shade cloth that offered 80% light impedance at one site and corrugated iron, which provided a total non-transparent cover at the other site. Shade covered approximately 18% of the total pen area.

Sanders et al. (1994) found the most important factors that had the most significant effect on daily water consumption in decreasing order of importance to be:

- solar radiation.
- relative humidity.
- average daily temperature.
- rainfall.
- dry matter intake.

Sanders et al. (1994) developed a predictive daily water consumption model based on rainfall, dry matter intake, shading and a weather factor that is a function of average daily temperature, solar radiation and relative humidity. Their model is:

$$\mathbf{WC = 1.337 + -0.037 \text{ x } P + 0.687 \text{ x } DMI + (1.592 + -0.199 \text{ x } \text{SHADING}) \text{ x } (\text{WEATHER})^{0.5}. \text{ - EQUATION 5}}$$

Where:

WC = water consumption (litres per day per 100 kg LWT)
DMI = dry matter intake (kg DM per day per 100 kg LWT)
P = Rainfall (mm)
Weather = average daily temperature (°C) x solar radiation (MJ/m^2)/relative humidity (%)
Shading = 0 for unshaded pens, 1 for shaded pens.

Sanders et al. (1994) found that the models developed by Hicks et al. (1988) and Winchester and Morris (1956) poorly modelled their collected data. The relationship developed by Sanders et al. (1994), whilst providing a better estimate of water intake, has limitations in that the climatic parameters required can only be obtained retrospectively i.e. daily rainfall, humidity, solar radiation. Therefore its use as a predictive model in situations where only limited climate data is available such as mean daily temperature or average total rainfall is limited. In addition, their study was only for a short period over summer months, thus not providing water consumption over a full yearly cycle of temperature.

A review of the work of Sanders et al. (1994) is contained in the FLOT.328 Final Report Part E ‘Review of lot fed cattle water consumption’.

Diurnal water consumption patterns found by Sanders et al. (1994) in their study are shown in Figures 5 and 6 for an unshaded and shaded pen respectively. The data has been normalised to a Standard Cattle Unit (SCU). Heat load index as developed by Gaughan et al. (2004) and ambient temperature are also presented along with feeding times. The typical daily variation is characterised by very low consumption in the period 3 am – 5 am, followed by greatest water consumption within the period 6 am – 6 to 8 pm, low water consumption from 8 pm – 9 pm for 1-2 hours then increased water consumption from 9 pm for 2-3 hours, then a gradual in water consumption to minimal levels by 3 am.

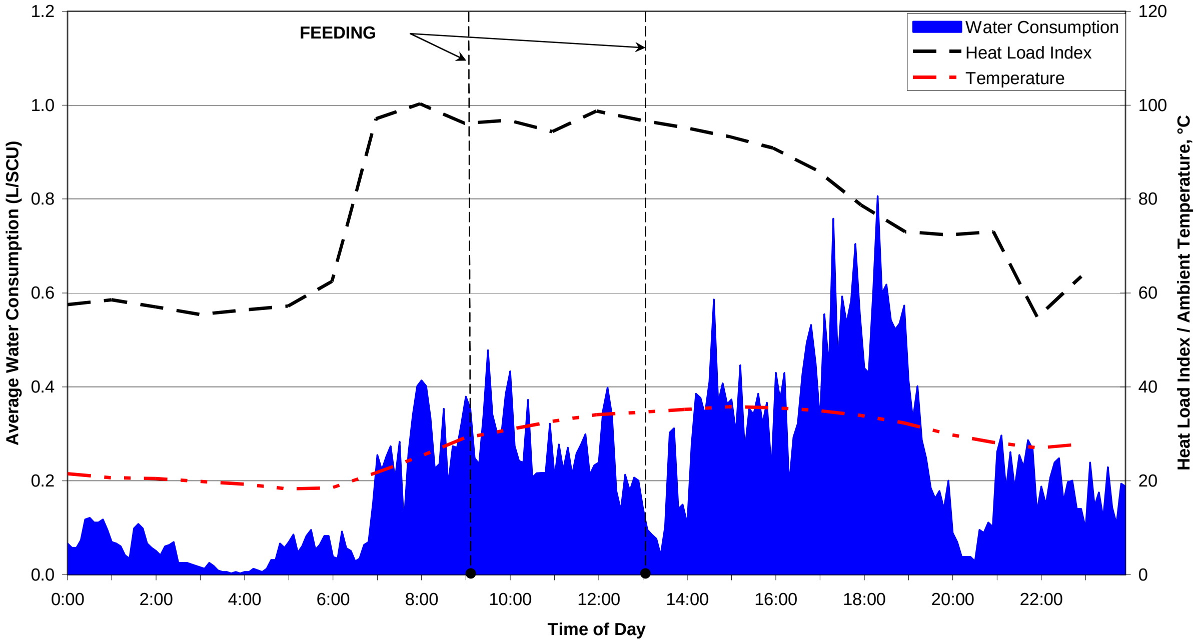


FIGURE 5 – DAILY VARIATION IN FEEDLOT WATER CONSUMPTION – UNSHADED PEN (07/01/1994)

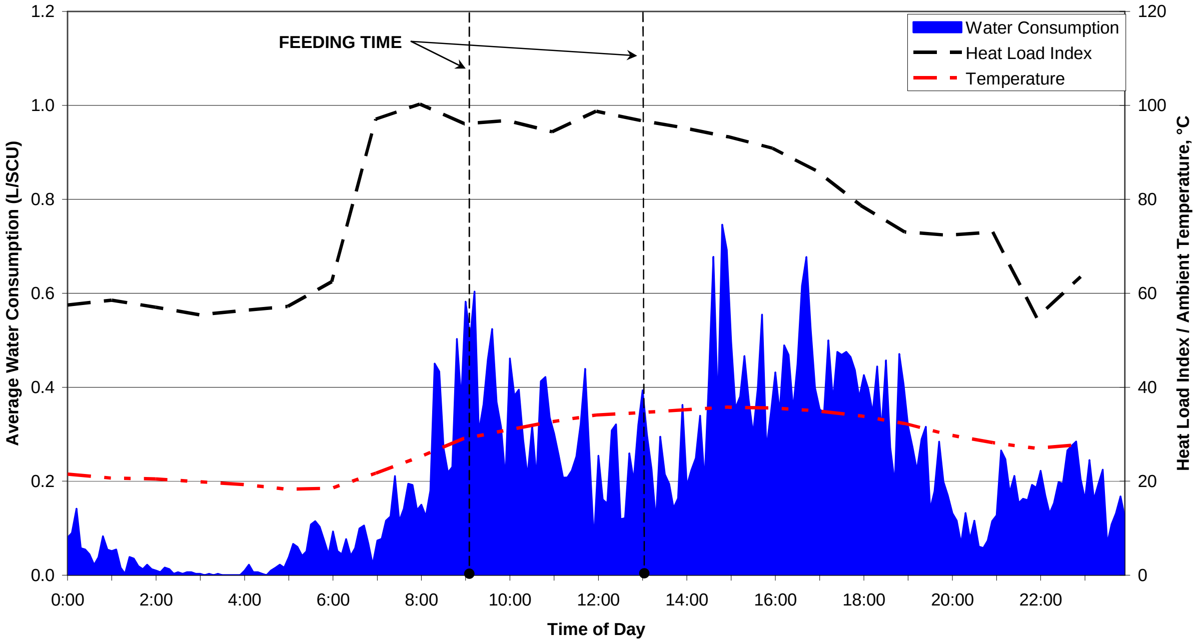


FIGURE 6 – DAILY VARIATION IN FEEDLOT WATER CONSUMPTION – SHADED PEN (07/01/1994)

4.3 Losses from Water Troughs

Water losses at troughs occur from water lost (dumped) during trough cleaning, evaporation from the air-water interface and sundry pipeline or float fault leakages.

Parker et al. (2000) measured water usage over a two-year period at a 50,000-head beef cattle feedlot in the Texas High Plains. Cattle types, mean liveweights and dry matter intakes were not reported. For a three-day period representing summer conditions, an average of 43.9 L/head/day was used. The breakdown of the usage was:

Drinking	39.0 L/head/day	(88.97%)
Cleaning troughs	0.3 L/head/day	(0.65%)
Feed mill	1.5 L/head/day	(3.35%)
Evaporation from troughs	0.02 L/head/day	(0.05%)
Leakage	3.1 L/head/day	(6.98%).

In winter, over a three-day period, the water usage was 51.8 L/head/day as per:

Drinking	34.1 L/head/day	(65.6%)
Cleaning troughs	0.3 L/head/day	(0.55%)
Feed mill	1.1 L/head/day	(2.16%)
Evaporation from troughs	0.02 L/head/day	(0.04%)
Trough overflow	16.4 L/head/day	(31.68%).

The high trough overflow usage is an intentional flow of water used to prevent freezing of the water troughs. This clearly would not apply in Australia.

No similar measurements have been made in Australia but estimates could be made. Consider a 15,000 head feedlot near Dalby on the Darling Downs. As a general rule of thumb, 30 mm of water trough length is required per head of cattle in the pen (Skerman 2000). Hence for a 200 head pen, it would be typical to have a single water trough that is 6 m long and 0.6 m wide. The surface area of the water trough would be 3.6 m^2 and the volume would be approximately 1080 L. A conservative assessment of the evaporation loss would be to assume that the loss is equal to pan evaporation – the water trough being of similar volume and depth to a Class ‘A’ pan – and that there is no net replenishment from rainfall (rainfall overtops the water trough). Hence, the annual evaporation loss would be 2000 mm/year or 7200 L from the trough. This is equivalent to 0.10 L/head/day assuming that the pen is full all year round. If the average pen occupancy is only 75% but the water trough is full all year round, the net evaporation loss would be 0.13 L/head/day. This data is five times higher than that presented by Parker et al. (2000) but as discussed in Section 4.2.2, water troughs in the US are often smaller in surface area to reduce the likelihood of freezing (see Photograph 3).

We assume that the water troughs are cleaned at least twice a week. During cleaning, the whole volume of the trough is dumped (~ 1080 L) and the system flows vigorously (at 0.7 L/s) for 3 - 4 minutes. Hence, it is estimated that about 1200 L of water is lost during trough cleaning. Over a whole year, this equates to 125,000 L. At 100% occupancy, this is 1.7 L/head/day. The water loss at

75% occupancy would be 2.3 L/head/day since water trough cleaning is not necessary if cattle are not in the pens.

Data collected by Sanders et al. (1994) indicated that losses during trough cleaning were typically between 144–324 L with an average of 236 L per trough per cleaning for a 220 L trough. In this case, the troughs were cleaned twice per week and therefore losses over a whole year, equate to approximately 24,500 L per trough. The pen capacity was 240 head, therefore at 100% occupancy losses due to trough cleaning were 0.28 L/head/day.

Losses associated with trough cleaning are therefore a function of trough capacity, as water troughs are completely emptied during cleaning. Larger capacity troughs have higher losses than smaller troughs.

In summary, water loss by trough evaporation and cleaning is estimated as 0.28-2.3 L/head/day. The lower value is similar to that found by Parker et al. (2000), however the higher value is over five times that found by Parker et al. (2000).

PHOTOGRAPH 2 – TYPICAL AUSTRALIAN FEEDLOT WATER TROUGH

Note: Overflow pipe to cater for faulty float valves and the brush beside the water trough that is used to clean the algae and grain from the trough.

PHOTOGRAPH 3 – NORTH AMERICAN FEEDLOT WATER TROUGH

Note: Small surface area of trough is designed to prevent freezing in winter.

4.4 Cattle Washing Prior to Dispatch

Washing cattle prior to dispatch to processing works is carried out in some feedlots. It is used to prevent faecal contamination of carcasses. However, information and data on the amount of water used for this purpose in Australia is extremely limited. Debate is ongoing about its efficacy in removing dirt and dags from the animal. Some lot feeders believe that no amount of washing will remove all residues from the animal, with manual shearing the only option.

Cattle washing systems can be automated or manual, or a combination of both. No published literature was found giving information on the amount of water used to wash cattle.

An estimate can be made using anecdotal evidence for lot feeders. One feedlot manager washes cattle in groups of about 32 x 700 kg head. The flow rate is 3.8 L/s (3000 GPH). This is a relatively low flow rate so he holds the cattle in the pen for 4 hours. This is a total volume of about 54,400 L or 1700 L per head. All of this water is clean water as no wastewater recycling is used. However, cattle washing is not required all year round. This feedlot manager estimates that he only washes 25% of outgoing cattle. For the number of cattle turned off from this feedlot per year, this is equivalent to 1.2 L/hd/day. Other managers use higher flow rates, shorter holding periods and wash different proportions of cattle turned off. All of these parameters affect the volume of water used for cattle washing. Another important variable is the ability to recycle wash water. If, say, 80% of the washing water is recycled back to the cattle wash, then this significantly reduces the demand for clean water.

PHOTOGRAPH 4 – WASHING CATTLE PRIOR TO DISPATCH

4.5 Evaporation Losses from Holding Storages

It is usual practice at feedlots to hold a few days supply of drinking water in a storage adjacent to the feedlot. This provides security of supply should there be a major breakdown in a pump or pipeline coming from a bore or river. Typically some 5-20 days water supply is kept on hand. This is often stored above ground in a turkey's nest storage (see Photograph 5) although enclosed steel or concrete tanks are sometimes used.

For an open storage, some water is lost by evaporation. The net evaporation loss would be estimated as:

$E = \text{Open water pan coefficient } (K_{OW}) \times \text{pan evaporation } (E_P) \text{ less rainfall } (P)$

The evaporation loss for Dalby (for example) could be estimated as follows. Mean annual pan evaporation is about 2000 mm and mean annual rainfall is about 600 mm. Weeks (1983) derived the open water pan coefficients for several sites in Queensland. For Dalby, K_{OW} would be 0.74 (Weeks 1983). Thus,

$$\begin{aligned} E &= (0.74 \times 2000 - 600) \text{ mm/yr} \\ &= 880 \text{ mm/yr} \end{aligned}$$

For a 15,000 head feedlot, 7 days of temporary storage would be about 8 ML. A turkey's nest storage of this capacity would have a surface area of about 2500 m^2. Hence, with a net evaporation loss of 880 mm per year, this represents 1.8 ML/yr or 5000 L/day on average. This is about 0.4 L/head/day, which is a minor water loss compared to drinking water intake.

PHOTOGRAPH 5 – TURKEY'S NEST WATER STORAGE

4.6 Feed Preparation

Processing grain significantly improves its digestibility for beef cattle. The ability of rumen microbes to digest grain is primarily dependent on particle size and the integrity of the outer protein matrix that surrounds starch granules in the endosperm. The order of response of different grains to the extent of processing is sorghum > corn > barley > triticale > wheat. Therefore, more aggressive processing technologies (requiring greater capital and operational input associated with steam flaking or extended fermentation) are required to effectively process sorghum and corn, compared to wheat, triticale and barley (which are better suited to rolling with or without tempering), if the greatest possible metabolisable energy is to be utilised by the feedlot animal.

The amount of water used in feed preparation depends upon the feed preparation process used. The different feed preparation processes can be broadly defined into two groups: 'wet' (e.g. steam flaking, reconstitution, tempering) and 'dry' processing (rolling). The determining factor is obviously whether water is added.

4.6.1 Tempering

Tempering involves adding moisture to the kernel and allowing it to steep for several hours before rolling. This process toughens the bran coat and causes it to separate more completely from the endosperm during the rolling process.

When grains are processed using tempering improvements in feed efficiency occur. Tempering usually results in grain with moisture content between 18% and 22% compared to normal grain, with a moisture content of about 12%.

Increasing the moisture content of grain to between 18-22 % during the tempering process requires water. Each tonne of grain might have an initial moisture content of 12 %, meaning that it comprises 120 kg of water and 880 kg of dry matter. Raising the moisture content of this tonne from 12 % to 18 - 22 % requires the addition of some 73-128 L of water. This equates to 0.073-0.128 kg (L) water per kilogram of feed.

Factual data on the volume of water required for tempering is difficult to obtain. However it is estimated that the water used in tempering is similar to the amount of water added to the grain (Doyle pers com).

4.6.2 Steam Flaking

Steam flaking subjects the grain to steam under atmospheric conditions for usually 15 to 30 minutes, before rolling. The flaking process causes gelatinisation of the starch granules (hydration or rupturing of the starch molecule) rendering them more digestible. The degree of flaking and level of gelatinization appear to be influenced by such factors as steaming time, temperature, grain moisture, roller size and tolerance, processing rate, and type and variety of grain. A typical steam flaker is shown in Photograph 6.

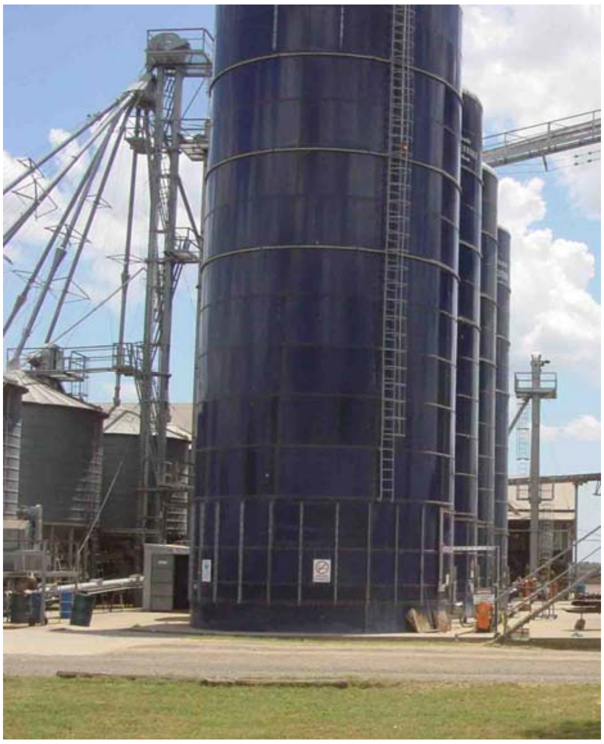
Steam flaking usually results in a grain with moisture content similar to that of tempered grain, between 18-22 %. During the flaking process large quantities of water can be lost as escaping steam. Data on water use for this process is difficult to obtain but it is estimated that the water requirement is some 2-3 times the amount of water added to the grain (Powell 1994).

Raising the moisture content of a tonne of grain with a moisture content of 12 % up to 18 % - 22 % requires the absorption of approximately 73-128 L of water. However, three times as much water may be required.

PHOTOGRAPH 6 – TYPICAL STEAM FLAKER

4.6.3 Reconstitution

Reconstitution usually results in grain with a moisture content of 28% to 32% compared to normal grain, with a moisture content of about 12%. This higher moisture content can be achieved by harvesting at 28% to 32% moisture or by adding water (reconstituting). Typical reconstitution silos ('Harvestore' silos) are shown in Photograph 7.



PHOTOGRAPH 7 – TYPICAL RECONSTITUTION SILOS

In both cases, the grain must be stored in the absence of air. Ideally, the high moisture grain must be stored for at least 10 days before feeding. The storage process is an ensilage process, which changes the nature of the endosperm thus improving digestibility. Ensiling high-moisture grain seems logical, because it gives the feedlot the option to feed a rapidly fermentable grain source that does not require steam flaking.

There is limited available data on losses associated with reconstituting grain. Anecdotal evidence suggests that losses associated with reconstitution can be up to 25% of the water added to the grain.

Increasing the moisture content of one tonne of grain from around 12% to an average 30 % moisture content requires approximately 257 kg of additional water. Hence, 257 kg of additional water is added for each tonne grain processed, or 0.257 kg (L) water per kg of feed.

Table 1 shows the estimated clean water use for reconstituting various grains. This information was compiled from 12 months of grain processing data provided by an Australian feedlot. This data along with information provided on ration composition and feed intake allowed average daily water use in terms of per head per day.

TABLE 1 – ESTIMATED WATER USE FOR RECONSTITUTING VARIOUS GRAINS

Grain Type		Barley	Corn	Sorghum
Initial moisture content, %		12.51	12.33	12.51
Final moisture content, %		29.81	29.22	29.32
Average Total Water used	(L/kg grain)	0.275	0.325	0.277
Average Total Water loss	(L/kg grain)	0.029	0.086	0.041
Maximum Water Loss	(L/kg grain)	0.119	0.258	0.200
Minimum Water Loss	(L/kg grain)	0.007	0.006	0.003
Water Used	(L/kg as fed)	0.169	0.163	0.162
Water Loss	(L/kg as fed)	0.020	0.059	0.028
Water Used	(L/hd/day)	2.18	2.11	2.09
Water Loss	(L/hd/day)	0.043	0.125	0.058
Percentage Water Loss	(%)	1.9	5.9	2.8

The average, maximum and minimum water loss was determined and presented in Table 1. Table 1 shows that average water used for reconstituting sorghum was 277 L per tonne of grain. The water loss associated with this ranged from 3-200 L per tonne of grain with an average of 41 L per tonne. Therefore, based on information provided in Table 1, it is estimated that 15% more water is required over that added to the grain.

Table 2 provides examples of estimated water use per head for various grain preparation processes. These examples are based on the assumption that grain generally makes up 75% of a diet for feedlot cattle and that a 450 kg domestic class animal will consume approximately 13 kg of feed (as fed) per day. The wastage factor indicates the amount of water used above that added to the grain. Hence, a wastage factor of 1 indicates that the total water usage is equal to the water added to the grain. A wastage factor of 2 indicates that the total water usage is twice the mass of the water added to the grain.

Table 2 estimates that, depending on the treatment method and daily intake; water used to process grain could be in the range of 0.9 to 2.7 L per head per day.

TABLE 2 – ESTIMATED WATER USE PER HEAD FOR GRAIN TREATMENT

Processing Method		Tempering	Steam Flaking	Reconstitution
Final Moisture Content		20%	20%	30%
Water wastage factor		1	2.5	1.15
Water Used	(L/kg grain)	0.10	0.25	0.30
Water Used	(L/kg as-fed)	0.06	0.15	0.22
Water Used	(L/hd/day)	0.98	2.44	2.9

Assumptions: Initial grain moisture content is 12% and ration is 75% grain. Daily intake (as-fed) is 13 kg/head/day.

Parker et al. (2000) monitored water usage at a 50,000 head feedlot. The average daily water use at the feed mill was measured separately. It was 55.8 m^3/day in April and 73.0 m^3/day in May. An average of 1.5 L/head/day was used in the feed mill based on 12 months of available feed mill water use data. The feed processing method was steam flaking and it is reasonable to assume that, for a feedlot of this size, the grain would be flaked corn. The estimates above are a little higher than this measurement of Parker et al. (2000).

4.7 Administration

On average, each member of staff may consume about 150 L of water per day through toilet flushing, washbasins and kitchen and laundry uses. A rule of thumb guide for the number of staff required for a feedlot is 1.2 person per 1000 head of capacity. Hence the water used by staff is equal to 0.18 L/head/day.

4.8 Supplementation / Dilution of Effluent Irrigation

The quantity of water used for supplementation or dilution of effluent for irrigation is highly variable between feedlots. Some feedlots use evaporation as the primary means of effluent disposal and do not require additional water for irrigation. Where effluent is reused for irrigation of crops, the amount of additional clean water required depends on the ‘strength’ of the effluent being irrigated and the area of land to which it is applied. An example of an effluent irrigator is shown in Photograph 8.

To illustrate generally, if 50 ML of effluent was to be reused through land irrigation with a 50 % dilution rate, then 50 ML of clean water would be required.

As most feedlots in Australia are outdoors, the occurrence and quantity of effluent generated is dictated by the weather conditions at the particular site. Hence it is very difficult to generalise the amount of water used in supplementing effluent irrigation in Australian feedlots.

The amount of effluent produced at any particular feedlot can be modelled using MEDLI (Gardner et al. 1996) using site-specific weather data combined with numerous feedlot-specific variables. MEDLI® is a Windows® based computer model for designing and analysing effluent disposal systems for intensive rural industries, agri-industrial processors (e.g. abattoirs) and sewage treatment plants using land irrigation. MEDLI models, on a daily basis, the effluent cycle from its production in the feedlot through to the disposal area and predicts the fate of the water, nitrogen, phosphorus, and soluble salts.

It must be noted that if clean water supplies are limited in a particular area, then the allocation of clean water for dilution of effluent is considered a low priority. In these cases, especially in Australia, effluent treatment systems would be designed with evaporation as the primary means of effluent disposal, requiring no additional clean water.

PHOTOGRAPH 8 – EXAMPLE OF CENTRE PIVOT IRRIGATOR APPLYING EFFLUENT

5 Data Collection and Analysis

5.1 Survey Data

As part of the FLOT.328 project, a detailed survey of feedlot inputs and outputs was undertaken to collect the data required for the life cycle inventory (see Section 3.4). The survey was conducted on-line.

For this report, the relevant data collected included:

1. Data on the number of incoming and outgoing cattle, intake and sale weights, dressing percentages and other parameters that allow HSCW gain to be estimated for two years (2002 & 2004).
2. Total clean water usage (ML/yr) and where possible individual sector usage broken up by drinking water, cattle washing, feed processing, administration, dilution of effluent irrigation for two years (2002 & 2004).

Most feedlots were able to provide good quality data on incoming and outgoing cattle numbers, production and total clean water usage.

Total clean water usage was well documented as most feedlots had meters on their water supplies (bores, river pumps). However, after consultation with individual respondents it was established that the data provided on individual sectors was in most cases no more than a best estimate breakdown from the total water usage. Hence, more information is required on the water usage of individual components before these figures can be reliably reported.

Hence, it was possible to estimate annual clean water usage in terms of HSCW gain (kg) and per 1000 head of pen capacity.

5.2 Sources of Water

The survey indicated that the following sources of water were used at feedlots.

- Bores
- River allocations
- Farm dams
- Irrigation channels
- Reticulated supply.

5.3 Data Analysis

After data was entered into the survey by lot feeders, the data was entered into a large Feedlot System Analysis Model spreadsheet (FSA Model) where various parameters were calculated and data quality checks were undertaken. Where anomalous data was detected, the participating feedlot was contacted and the data was examined in more detail.

However, in some cases there still remained a mismatch between the mean number of cattle on hand estimated by the FSA model and that given in the survey. In most cases this was due to the yearly cattle number data and summary mean cattle on hand entered into the survey which does not capture monthly fluctuations. The following discussion outlines potential errors in the data.

Firstly, HSCW gain was calculated from the survey data of cattle numbers in, entry weight, total liveweight in, cattle numbers out, exit weight and total liveweight out and mortality numbers. Secondly, HSCW gain was estimated by the spreadsheet model from the model estimated number of cattle in, entry weight from survey and model estimated number of cattle out, exit weight from survey and mortality numbers from survey. In both cases, an estimate of dressing percentage in and out was required.

The mean number of cattle on hand on the 1st and last day of each survey year was required to be input into the survey. The average of this was used as the survey mean number of cattle on hand. This was compared with the FSA Model estimated mean number of cattle on hand and the difference presented in Figure 7 and Figure 8 from 2002 and 2004 respectively.

Figure 7 and Figure 8 illustrate the percentage difference between the HSCW gain calculated from the survey data and estimated from the spreadsheet model and the difference between mean number of cattle on hand input into the survey and that estimated from the spreadsheet model for the 2002 and 2004 calendar years. A positive difference results from the FSA Model underestimating values and similarly a negative difference results from the model overestimating values when compared with survey data.

Figure 7 and Figure 8 illustrate that feedlots were able to provide very good estimates of total cattle numbers in and out and total liveweight in and out, therefore errors between HSCW gain as calculated from survey data and that estimated from the FSA Model are typically less than 1%, with the exception of Feedlot 3 and Feedlot 6 in 2002. Hence, results standardised per kg HSCW gain have small inherent errors, with the exception of Feedlot 3 and 6 in 2002.

Errors were found between the mean number of cattle on hand as determined from survey data and that estimated from the FSA Model across all feedlots. Errors ranged from –9% to 24% and –20 to 55% for the 2002 and 2004 survey years respectively. Hence, results calculated from or based on mean number of cattle on hand potentially have large inherent errors.

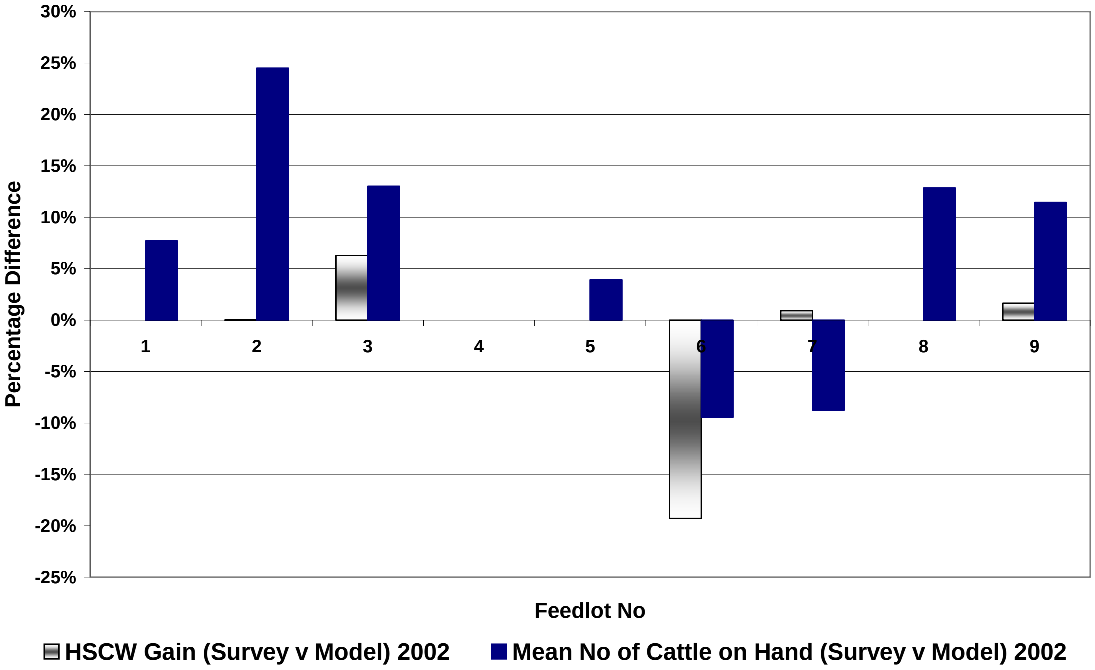


FIGURE 7 – PERCENTAGE DIFFERENCE BETWEEN SURVEY DATA AND MODEL ESTIMATION FOR 2002 SURVEY YEAR

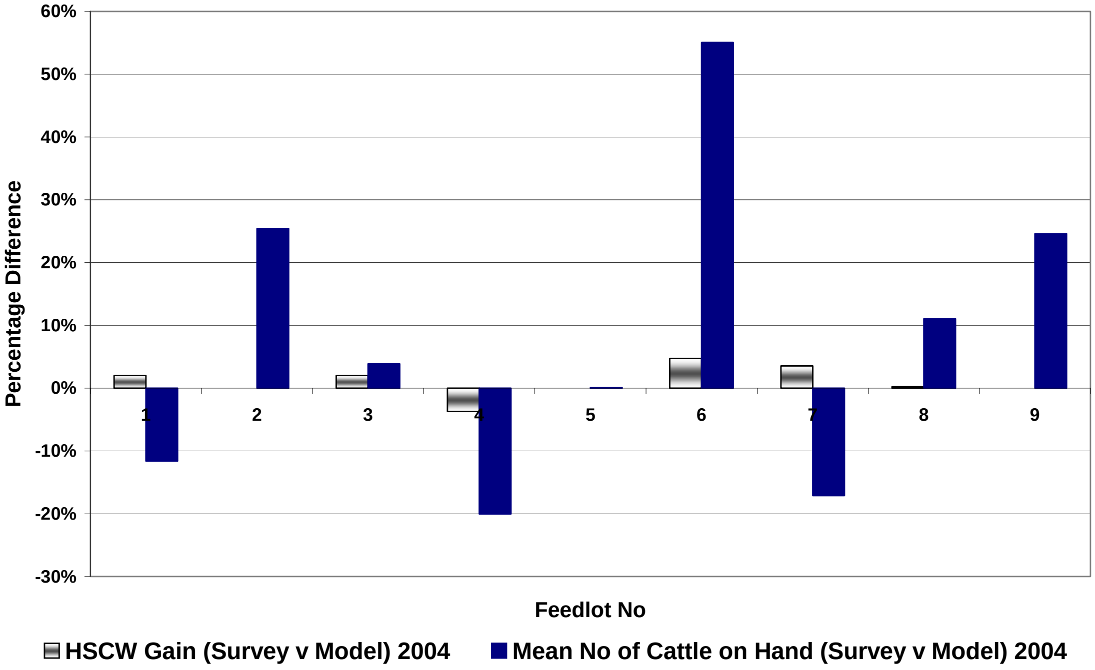


FIGURE 8 - PERCENTAGE DIFFERENCE BETWEEN SURVEY DATA AND MODEL ESTIMATION FOR 2004 SURVEY YEAR

6 Results and Discussion

6.1 Total Water Usage

Total annual clean water use from each water supply source was required to be input into the survey along with a breakdown of water use into components. The drinking water, cattle washing, feed processing and administration components were totalled and then standardised per kg HSCW gain. Figure 9 illustrates the total annual water use without dilution of effluent irrigation. Feedlots 7, 8 and 9 also had a dilution of effluent irrigation component of water use, however this is not included in Figure 9. Feedlot 2 was unable to supply annual water use figures and Feedlot 6 could only supply a combined total water use. All feedlots, except No 2 had meters on all their water sources. Hence total water use can be considered accurate.

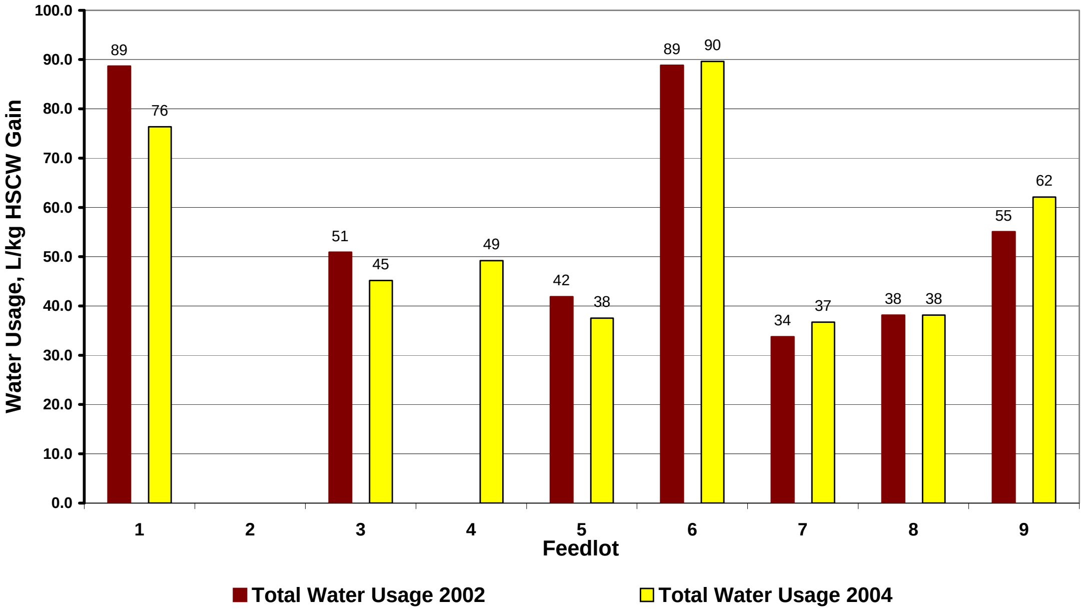


FIGURE 9 – TOTAL WATER USE PER KILOGRAM OF HSCW GAIN FOR 2002 AND 2004 SURVEY YEARS (WITHOUT DILUTION OF EFFLUENT IRRIGATION)

Figure 9 shows that annual water use ranges from 34 to 89 L/kg HSCW gain for the 2002 survey year and ranged from 37-90 L/kg HSCW gain in the 2004 year. Hence, total water use is similar for both years. Variation between feedlots may be explained by management operations including frequency of trough cleaning, cattle washing, dust control and feed processing.

Figure 10 illustrates the total annual water use with dilution of effluent irrigation included. It shows that annual water use ranges from 42 to 381 L/Kg HSCW gain for the 2002 survey year and ranged from 38-381 L/kg HSCW gain in the 2004 year. Feedlots 1 and 8 demonstrate the impact of the availability of water for dilution of effluent. Feedlot 8 is a small feedlot, with a plentiful supply of water available for dilution of effluent. Hence this increases its water usage per kg/HSCW nearly five times when compared with the remaining feedlots. Feedlot 1 is a large feedlot, which used water for dilution of effluent in 2004 and not in 2002. In this case water usage increased from 89 to 133 L/kg HSCW gain.

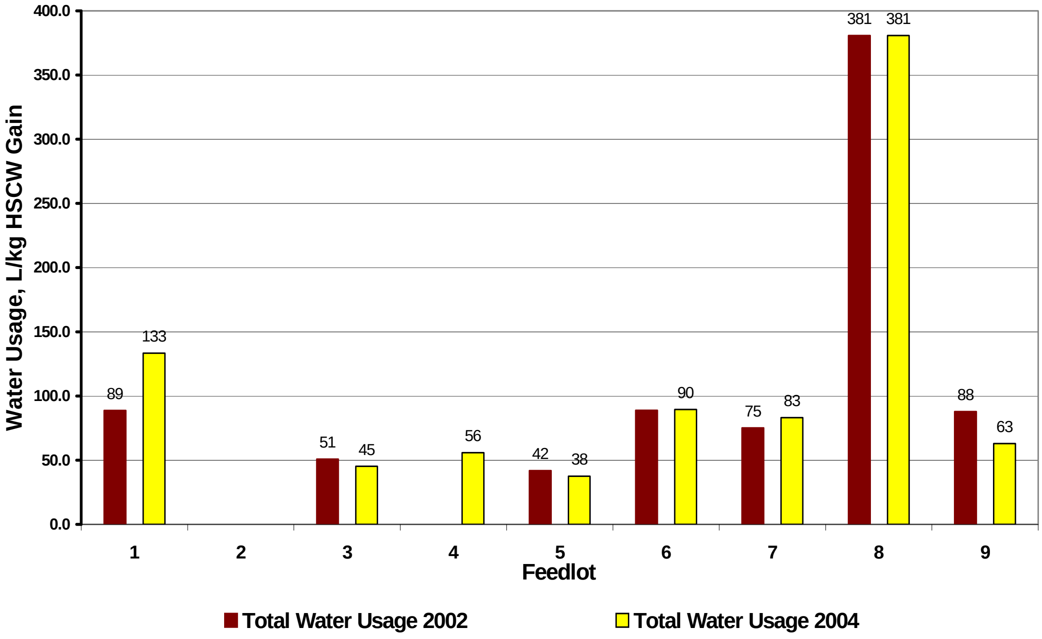


FIGURE 10 - TOTAL WATER USE PER KILOGRAM OF HSCW GAIN FOR 2002 AND 2004 SURVEY YEARS (WITH DILUTION FOR EFFLUENT IRRIGATION)

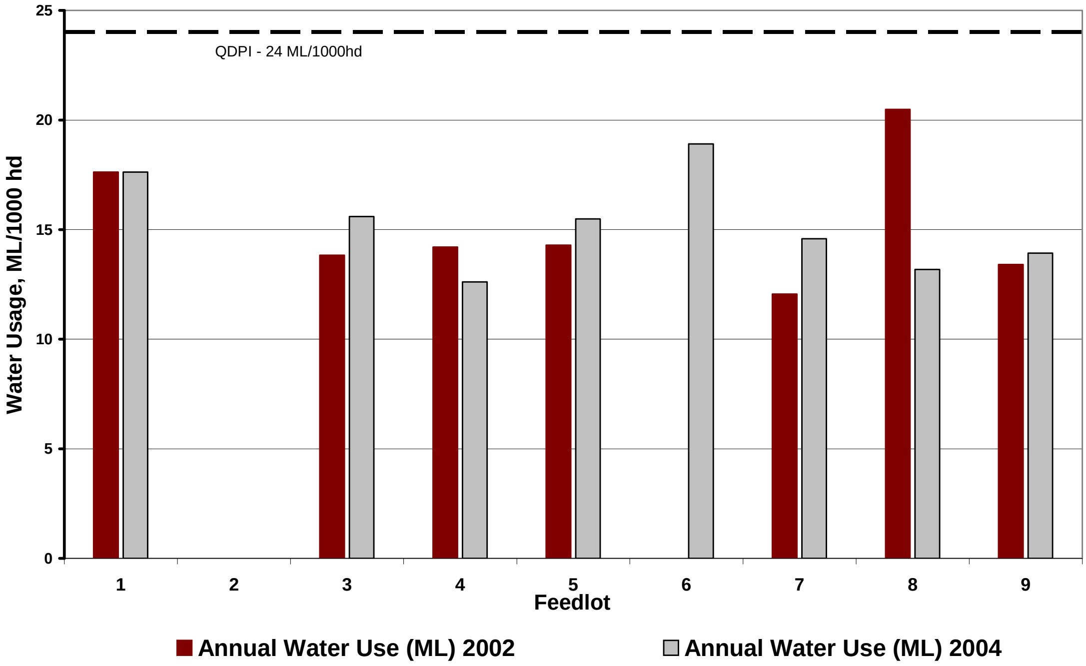


FIGURE 11 –TOTAL WATER USAGE PER 1000 HEAD OF LICENSED PEN CAPACITY FOR 2002 AND 2004 SURVEY YEARS

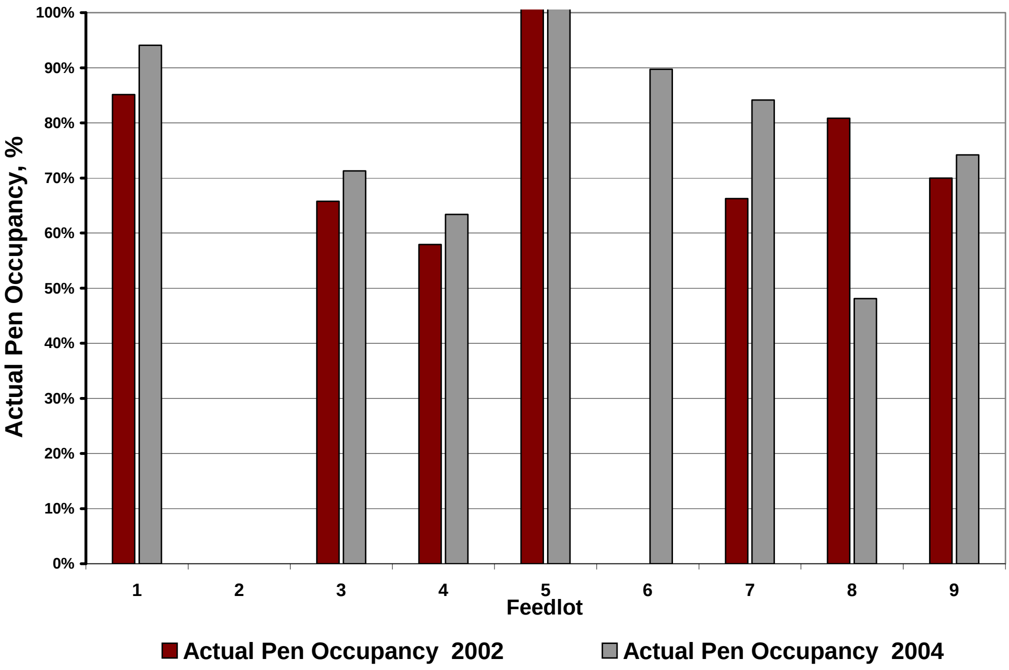


FIGURE 12 – ACTUAL PEN OCCUPANCY FOR 2002 AND 2004 SURVEY YEARS

When issuing a licence for a feedlot in Queensland, Queensland Department of Primary Industries and Fisheries (QDPI&F) requires that the feedlot has a correctly licensed, high-reliability water supply equivalent to 24 ML per year for each 1000 SCU of licensed capacity. Figure 11 illustrates the total annual water use per 1000 head of pen capacity. (Head is used rather than SCU for those states where SCU does not apply). It shows that annual water use per 1000 head ranges from 12 to 17 ML for the 2002 survey year and ranged from 12 to 20 ML in the 2004. In both years, the annual water use is below that required by the QDPI&F. Figure 12 illustrates the actual pen occupancy percentage during the 2002 and 2004 survey years. Actual pen occupancy percentage has been defined as the mean number of cattle on hand divided by the licensed pen capacity for the respective year.

6.1.1 Individual sector water usage

Water usage from individual sectors of the feedlot viz drinking water, feed processing, cattle washing and effluent dilution was required to be input into the survey. After consultation with individual respondents, it was established that the data provided on individual sectors was, in most cases, no more than a best estimate breakdown from the total water usage. Therefore, if a component was overestimated viz drinking water, than this translates into an underestimation of usage from remaining sectors. Hence, more information is required on individual sectors before these figures can be reliably reported.

7 Conclusions and Recommendations

7.1 Conclusions

Little work has been undertaken to evaluate total water consumption by feedlots. The amount of drinking water used at feedlots has been studied in North America in the 1980's. To date, only a limited study on drinking water requirements has been undertaken in Australia. Water is both the most important nutrient for cattle and the most valuable natural resource (after land) in Australia. Hence, it is of critical importance to lot feeders.

Little information exists on the water usage of individual components of the feedlot system, viz drinking water, feed processing, cattle washing, administration and dilution of effluent irrigation. Factual information on water usage was collected on individual feedlot sector operations where possible.

The main factor determining total annual water use was the quantity of water used for dilution of effluent for irrigation.

Results from the nine feedlots studied showed that total annual clean water use (without dilution of effluent) ranged from 34-90 L/kg HSCW gain over the 2002 and 2004 survey years respectively with a median value of 73 L/kg HSCW gain. Hence, total water use is similar for both years. Variation between feedlots may be explained by management operations including frequency of trough cleaning, cattle washing, dust control and feed processing.

When dilution of effluent is included, the total annual clean water use ranges from 38 to 381 L/Kg HSCW gain for the 2002 and 2004 respectively. Hence, when a plentiful supply of water is available for dilution of effluent, water usage per kg/HSCW increases substantially. Other tools such as MEDLI are available for estimating the volume of clean water required for dilution of effluent.

Whilst, total annual clean water records by lot feeders are good, little data exists on actual usage levels in individual components, viz. drinking water, feed processing, cattle washing. After consultation with individual respondents, it was established that the data provided on individual sectors was, in most cases, no more than a best estimate breakdown from the total water usage. Therefore, if a component was overestimated viz drinking water, than this translates into an underestimation of usage from remaining sectors. Hence, more information is required on individual sectors before these figures can be reliably reported.

The outcomes of this study will allow the feedlot industry to start benchmarking total water usage, hence addressing the public misconceptions associated with the water used in the production of one kilogram of grained beef. In addition, this information is invaluable for future design and management considerations.

7.2 Recommendations

Whilst the type and detail of the information collected in this study allowed the total water consumption from feedlot operations to be estimated, few feedlots were able to accurately partition the water use into individual sectors. This information would be invaluable in optimising the design and management of cattle feedlots and in better explaining the natural resource use.

Hence, it is recommended that industry undertake further research into water consumption from individual feedlot sectors including feed processing, cattle washing and drinking water. The fact that large amounts of water are consumed in drinking water livestock is of course, well known to the industry. However, what factors influence daily water consumption and diurnal variation is not well known but may become important to the industry in a way it has not been before.

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Environmental Sustainability Assessment of the Australian Feedlot Industry

Part B Report – Energy Usage and Greenhouse Gas Emission Estimation at Australian Feedlots

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Abstract

The Australian red meat industry, as with most primary industries, is coming under increasing pressure from both the community and government to document and justify its impacts on the environment. This project addresses some public misconceptions about the environmental sustainability of the feedlot industry by identifying and quantifying the energy use and GHG emissions associated with the production of one kilogram of grained beef.

Energy is fundamental to a feedlot production system. Little work has been undertaken on energy use at feedlots and there have been no studies to date for Australian feedlots.

This project reviewed previous research into energy consumption and GHG emissions from feedlots. Factual data on energy use in Australian cattle feedlots under a range of climatic, size and management conditions was collected from nine feedlots over the 2002 and 2004 years. Greenhouse gas emissions were then estimated using Australian Greenhouse office standard methodology.

Executive Summary

The Australian red meat industry, as with most primary industries, is coming under increasing pressure from both the community and government to document and justify its impacts on the environment. Currently, a lack of credible supply chain data prevents the industry from being able to respond in a meaningful manner.

Meat and Livestock Australia (MLA) is undertaking a project (COMP.094) that will address these issues and provide credible data on the industry's environmental impacts and sustainability for use by industry, including its interactions with government, community groups and the media. This project will use the standardised tool, Life Cycle Analysis (LCA), to quantify natural resource consumption and environmental interventions to water, soil and air.

LCA is a form of cradle-to-grave system analysis developed for manufacturing and processing industries to assess the environmental impacts of products, processes and activities by quantifying their environmental effects throughout their entire life cycles. An LCA is essentially a quantitative study. Sometimes environmental impacts cannot be quantified because of a lack of data or inadequate impact assessment models. Quantitative analysis requires standardised databases of main processes (e.g. energy, transport) and software for managing the study's complexity.

As part of the overall industry project, the beef cattle lotfeeding sector is undertaking a related MLA project (FLOT.328) that will contribute to the whole of industry dataset, but more importantly address public misconceptions concerning the environmental sustainability of the feedlot industry. It will identify and quantify the environmental costs associated with the production of one kilogram of grained beef to enable comparison with its domestic competing products (grass fed beef, lamb, pig and poultry meats). This report has been prepared as part of FLOT.328. It addresses the issues of energy use and greenhouse gas (GHG) emissions by feedlots. It provides factual information on the quantity of energy used and an estimation of GHG emissions at Australian cattle feedlots under a range of climatic, size and management conditions.

Factual data to estimate energy use was obtained via a detailed on-line survey of feedlot inputs and outputs including cattle numbers, intake and sale weights, dressing percentages, mean distance travelled to and from the lot and energy consumption. Annual energy usage was estimated on the basis of one kilogram of hot standard carcass weight gain (kg HSCW gain). In this context, HSCW gain is the difference between total dressed carcass weight of cattle leaving the feedlot less the estimated total dressed carcass weight of cattle entering the feedlot.

The survey identified that energy was used both directly and indirectly by feedlots. Indirect energy use included that consumed in the transportation of cattle and commodities. Direct energy usage included that used by feed processing, feed delivery, water supply, irrigation, administration and other farming activities.

Distance travelled has a large impact on energy consumption through incoming and outgoing cattle and commodity delivery. Sourcing cattle and commodities close to feedlots and locating feedlots close to abattoirs minimises energy consumed in these processes. Cattle sourced close to feedlots have lower (0.5-1.25 MJ/kg HSCW gain) energy consumption when compared with feedlots that source cattle from greater distances (2.5-3.0 MJ/kg HSCW gain). Commodities sourced close to

feedlots have lower (0.5 MJ/kg HSCW gain) energy consumption than feedlots that source commodities from greater distances (1.5-3.5 MJ/kg HSCW gain).

Feed processing is the single largest consumer of energy in the feedlot sub-system and can account for up to 70% of the total energy consumption. The amount of energy needed for feed processing depends upon the processing system. Energy consumption ranges from 0.25 MJ/kg HSCW (tempering) to 4.4 MJ/kg HSCW gain (steam flaking). Feedlots that process their grain by steam flaking use more than nine times the energy for feed processing compared with those that reconstitute or temper their grain.

Feed delivery and pen cleaning/maintenance are the second largest energy consumers in the feedlot sub-system, accounting for 15% to 40% of total energy usage. Pen cleaning frequency, pen layout, location of pens in relation to the feedmill and feed truck age and type contribute to feed delivery/pen cleaning & maintenance energy consumption.

Energy used in water supply, administration, irrigation and other farming activities comprise the balance of the energy used in feedlots, at about 10% of the total energy consumption.

In 2002, total energy consumption was found to range from 1.14 to 17.8 MJ/kg HSCW gain. In 2004, energy consumption ranged from a minimum of 1.4 to a maximum of 12.8 MJ/kg HSCW gain.

GHG emissions were estimated using standard Australian Greenhouse Office (AGO) methodology for feedlots. This methodology does not appear to accurately reflect the manure and effluent management systems used at Australian feedlots and may underestimate GHG emissions, particularly from manure management. The conclusions drawn below are based on standard methodology. However we have no reliable data to support this. It is strongly recommended that research on GHG emissions from cattle feedlots be undertaken to refine the methodology.

Enteric methane emission represents the greatest single source of GHG emissions from the feedlot sub-system accounting for up to of 62% of total emissions. Enteric methane emission rates depend upon the class of cattle in the feedlot, with longer fed cattle (> 150 days) having a higher enteric methane production than shorter fed cattle (< 150 days) per unit of gain.

Nitrous oxide emission from manure represents the second largest source of GHG emissions from the feedlot sub-system accounting for up to of 26% of total emissions. Manure methane accounts for 2% of total GHG emissions. The default MCF value of 5% was used to calculate manure methane emissions for ‘warm’ regions (Queensland) and 1.5% for ‘temperate’ regions (NSW, Victoria). Thus, no consideration is given for anaerobic (wet pen) conditions in feedlot pens following rainfall. If the MCF for feedlot manure is closer to that estimated by Steed and Hashimoto (1995) of around 66% for a wet anaerobic pen surface, then the current AGO method under-estimates emissions from manure methane.

Combined emissions from the energy consumed during livestock and commodity transport, feed processing, feed delivery and water supply account for 10% of the GHG emissions. Of these sectors feed processing can have the highest emissions, depending on the type of processing system.

The data presented in this report was input into the life cycle inventory for the energy use and GHG emissions component of the feedlot sub-system for project COMP.094.

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1 Background

The Australian red meat industry, like most primary industries, is coming under increasing pressure from both the community and government to document and justify its impacts on the environment. This is evident through the government emphasis on industry initiatives, such as the implementation of Environmental Management Systems (EMS), and Triple Bottom Line (TBL) reporting requirements. Currently, a lack of credible supply chain data prevents the industry from being able to respond in a meaningful manner.

Meat and Livestock Australia (MLA) is undertaking a project (COMP.094) that will address these issues and provide credible data on the industry's environmental impacts and sustainability for use by industry, including its interactions with government, community groups and the media. This project will utilise the standardised tool, Life Cycle Analysis (LCA), to quantify natural resource consumption and environmental interventions to water, soil and air.

A separate but related project (FLOT.328) is being undertaken for the lot-feeding sector of the Australian red meat industry.

1.1 FLOT.328 Project Description

As part of the overall industry project, the beef cattle lotfeeding sector is undertaking a related project (FLOT.328) that will contribute to the whole of industry dataset, but more importantly addresses the public misconceptions of the environmental sustainability of the feedlot industry. It will identify and quantify the environmental costs associated with the production of one kilogram of grained beef to enable comparison with its domestic competing products (grass fed beef, lamb, pig and poultry meats).

Given that environmental sustainability will eventually become a key element in maintaining and improving access for Australian product into key overseas markets, it is envisaged that project FLOT.328 will also benchmark these costs against international competitors (US and European beef) and identify areas of R&D investment to ensure the long-term viability and sustainability of the feedlot production system. This study of energy usage and greenhouse gas (GHG) emission estimation at Australian feedlots is part of FLOT.328.

2 Project Objectives

The FLOT.328 project will:

1. Collect, collate and present relevant data to enable MLA to assess/benchmark the environmental sustainability of the feedlot industry against its domestic and international competitors by assessing the environmental costs associated with the production of one kilogram of meat from each production system
2. Provide data for the feedlot industry suitable for use within the broader red meat supply chain LCA (COMP.094)
3. Identify areas for potential future R&D investment to ensure long-term competitiveness, viability and sustainability of the feedlot production system
4. Communicate the results of the assessment to MLA in a format suitable for dissemination to industry stakeholders.

This report covers the issues of energy usage and GHG emissions by the feedlots production system. The report aims to provide factual information on the quantity of energy used in producing red meat within the feedlot sector, and an estimate of the GHGs emitted during this process.

2.1 Project Reporting Structure

This project includes the collection and analysis of a large quantity of data from operational feedlots on the environmental costs associated with the production of one kilogram of hot standard carcass weight (HSCW). In this context, HSCW gain is the difference between total dressed carcass weight of cattle leaving the feedlot less the estimated total dressed carcass weight of cattle entering the feedlot. To ensure all this data and information is presented in a suitable manner, six reports have been compiled.

A. Water Usage at Australian Feedlots. This report presents a background literature review of water usage at feedlots, data collection and results, as well as an analysis and discussion of the data collected. This report is the life cycle inventory for the water use component of the feedlot sub-system.

B. Energy Usage and Greenhouse Gas Emission Estimation at Australian Feedlots. This report presents a background literature review of energy usage and GHG emissions at feedlots, data collection and results. A discussion of results and the relative merits of the current GHG emission calculation methodology by the Australian Greenhouse Office (AGO) are included. This report is the life cycle inventory for the energy use and GHG emissions component of the feedlot sub-system.

C. Nutrient Cycling at Australian Feedlots*.* This report includes a literature review of nutrient pathways at feedlots, data collection and results as well as an analysis and discussion of the data collected. This report is the life cycle inventory for the nutrient cycling component of the feedlot sub-system.

D. NPI Listed Substances Emission Estimation for Australian Feedlots. This report provides a summary of the National Pollutant Inventory (NPI) reporting framework, data collection and results for category I listed substances. The report also includes a discussion of the relative merits of the current NPI emission estimation methodology, with guidance on an alternative method for use under Australian conditions.

E. Review of Lot Fed Cattle Water Consumption – MRC Project No. DAQ.079. This report provides a review of research undertaken in the early 1990's on water consumption in feedlots. It provides a more detailed literature review on the factors influencing drinking water requirements than is provided in Part A, experimental methodology, data collected and discussion of the results and outcomes of this MRC research.

F. Resource Use and Environmental Impact Assessment for Australian Feedlots. This report provides a summary of feedlot-relevant natural resources management (NRM) issues, data collection and results. A discussion of the environmental impact of the use of these resources by beef cattle feedlots is also included.

3 Life Cycle Assessment

MLA is undertaking a project (COMP.094) that will provide credible data on the red meat industry's environmental impacts and sustainability for use by industry, including its interactions with government, community groups and the media. This project will utilise the standardised tool, LCA, to quantify natural resource consumption and environmental interventions to water, soil and air. This project (FLOT.328) is being undertaken for the lot feeding sector of the Australian red meat industry. The following description of LCA is taken from Peters et al. (2005).

3.1 Description of Life Cycle Assessment

LCA is a form of cradle-to-grave systems analysis developed for use in manufacturing and processing industries to assess the environmental impacts of products, processes and activities by quantifying their environmental effects throughout the entire life cycle. LCA can be used to compare alternative products, processes or services; to compare alternative life cycles for a product or service; and to identify those parts of the life cycle where the greatest improvements can be made. An international standard has now been developed to specify the general framework, principles and requirements for conducting and reporting LCA studies (Standards Australia 1998). LCA differs from other environmental tools (e.g. risk assessment, environmental performance evaluation, environmental auditing and environmental impact assessment) in a number of significant ways. In LCA, the environmental impact of a product or the function a product is designed to perform is assessed, the data obtained are independent of any ideology and it is much more complex than other environmental tools. As a system analysis, it surpasses the purely local effects of a decision and indicates the overall effects.

There are four aspects of life cycle assessment (see Figure 1):

- *Goal and Scope Definition* defines the goal, functional unit and associated system to be studied.
- *Inventory Analysis* analyses all process inputs and outputs. It involves modelling unit processes in the system, considered as inputs from the environment (resources and energy) and outputs (product, emissions and waste) to the environment. Allocation of inputs and outputs needs to be clarified where processes have several functions (for example, where one production plant produces several products). In this case, different process inputs and outputs are attributed to the different goods and services produced. An extra simplification used by LCA is that processes are generally described without regard to their specific location and time of operation.
- *Impact Assessment* makes results from the inventory analysis more manageable and understandable in relation to natural environment, human health and resource availability.
- *Interpretation* involves evaluating inventory analysis and impact assessment outcomes against the study's goal.

An LCA is essentially a quantitative study. Sometimes environmental impacts cannot be quantified due to a lack of data or inadequate impact assessment models. Quantitative analysis requires standardised databases of main processes (energy, transport) and software for managing the study's complexity.

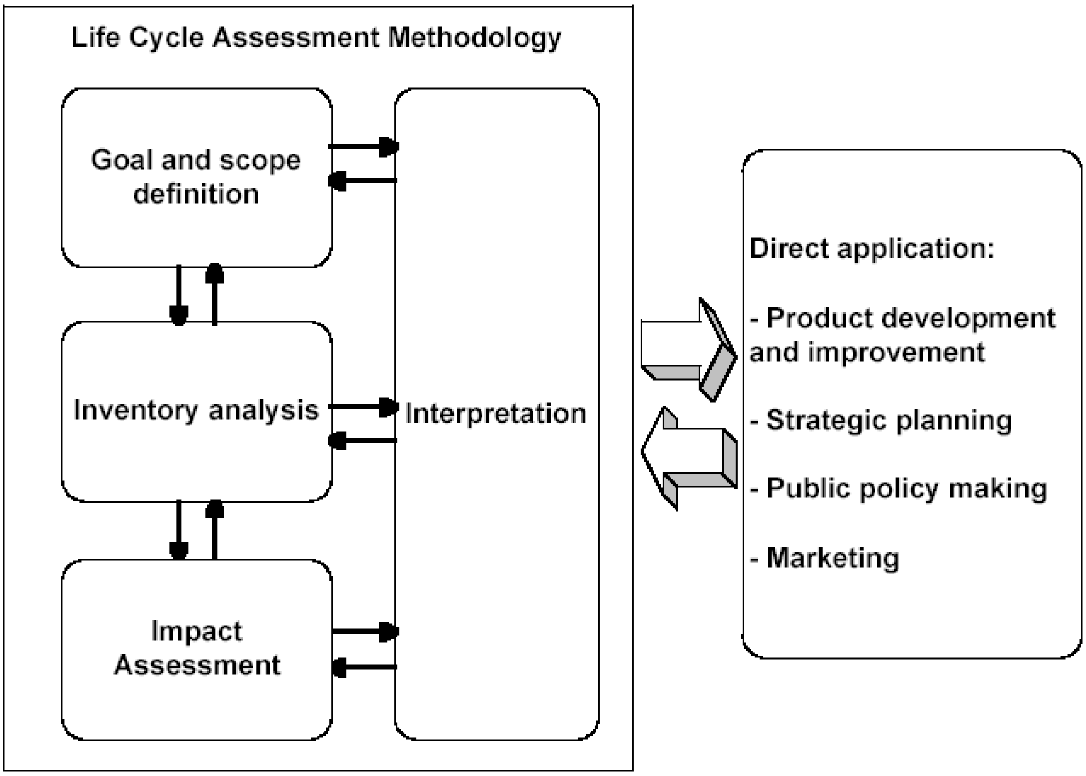


Figure 1 – General framework for LCA and its application (Standards Australia 1998)

3.2 Selection of Functional Unit

The functional unit for this study is the delivery of one kilogram of hot standard carcass weight (HSCW) meat at the abattoir. AUS-MEAT is the authority for uniform specifications for meat and livestock in Australia. In March 1987, they introduced the term HSCW as a national standard. The HSCW is the fundamental unit of "over the hooks" selling and is the weight, within two hours of slaughter, of a carcass with standard trim (all fats out). This is a carcass after bleeding, skinning, removal of all internal organs, minimum trimming and removal of head, feet, tail and other items (AUS-MEAT, 2001). "Hot" indicates that the meat in question has not entered any chilling operations. This output-related functional unit was chosen, rather than an input-related one, in order to describe the human utility of the processes under consideration – the provision of nutrition for people. Although the meat could be served in different ways, this functional unit makes the different processes under consideration "functionally equivalent" from a dietary perspective.

3.3 System Boundaries

In LCA methodology, usually all inputs and outputs from the system are based on the 'cradle-to-grave' approach. This means that inputs into the system should be flows from the environment, without any transformation from humans. Outputs should also be discarded to the environment without subsequent human transformation (Standards Australia 1998). Each system considers upstream processes with regard to the extraction of raw materials and the manufacturing of products being used in the system and it considers downstream processes as well as all final emissions to the environment.

Figure 2 shows the generalised system boundary for the red-meat sector as defined for the COMP.094 project. Within this boundary, there is a sub-system for the feedlot sector. The boundary chosen here (shown in red on Figure 2) is the feedlot site itself, plus the transport component of bringing cattle and feed into the feedlot and delivering cattle from the feedlot. The production of feed for the feedlot will be examined in a larger system analysis.

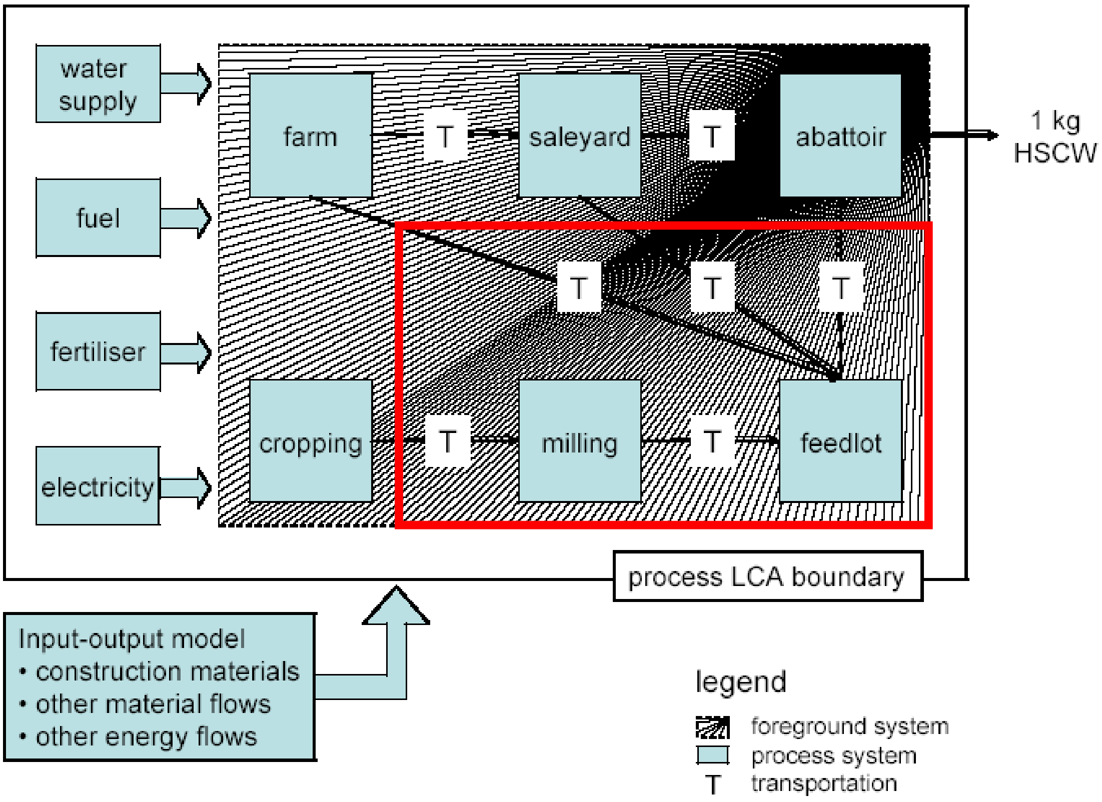


Figure 2 – Generalised System Model for the Red Meat Sector with Feedlot Sub-system

3.4 Life Cycle Inventory

Inventory analysis is the second phase in a life cycle assessment and is concerned with data collection and calculation procedures. The Inventory Analysis phase forms the body of the LCA, as the majority of time and effort in an LCA is spent on Inventory Analysis. As a rule of thumb, 80 percent of the time required for an LCA is needed for this phase. The operational steps in preparing a life cycle inventory (LCI) are according to ISO 14041 (Standards Australia 1999):

- Data collection.
- Relating data to unit processes and/or functional unit.
- Data aggregation.
- Refining the system boundaries.

This report is the life cycle inventory for the energy use and GHG emissions component of the feedlot sub-system.

4 Literature Review – Energy Use

4.1 Introduction

Energy is fundamental to a feedlot production system. Despite this, there has been little research into energy use by feedlots. Rather, the energy requirements of feedlots have been estimated from several studies undertaken in North America in the 1970's and 1980's. To date no such studies have been undertaken for Australian feedlots. For the purposes of this report, energy consumption can be classified into two categories, indirect and direct sources. Indirect sources arise mainly from the transport of cattle in and out of the feedlot, commodity delivery and manure removal. Energy is used directly in the operation of the feedlot for the production of beef – feed processing, feed delivery, water supply, office etc.

Gaining an understanding of the energy use within feedlots across the industry will allow for improvement, economic gain and future opportunities for the evaluation and identification of environmental sustainability indicators for GHG emissions.

4.2 Indirect Sources

Indirect energy consumption is fundamental to the operation of feedlots. It is central for the provision of incoming and outgoing livestock and for the delivery of feed commodities. Energy consumption inevitably produces waste that can be harmful to the environment, such as the emission of gases and particles from the burning of fossil fuels.

4.2.1 Livestock Transport

The energy or fuel consumed for transport of incoming and outgoing cattle can be significant and depends upon the types of vehicles used, fuel type/s, fuel efficiency, distance travelled and loading capacity. Most feedlots are located within a couple of hundred kilometres of abattoirs. However, incoming cattle can be sourced from sites thousands of kilometres away, especially for vertically integrated corporate feedlots.

Fuel efficiency in transport vehicles is measured by fuel usage over a set distance, traditionally litres of fuel per 100 kilometres travelled. Vehicle fuel consumption is a function of the efficiency of vehicle weight, vehicle motor technology, fuel technology and other factors. An ongoing interest in reducing transportation energy use has resulted in a continuing focus on fuel efficiency. Vehicle weight reductions and advances in technology have led to improvements in truck fuel efficiency.

Heavy vehicles over 10 tonnes gross vehicle mass (GVM) are predominantly used to transport livestock. These vehicles use turbocharged, four stroke compression ignition engines commonly referred to as 'diesel engines'. Photograph 1 illustrates a typical semi trailer livestock transport with two decks.

Photograph 1 – Typical semi trailer (2 decks) livestock transport.

4.2.2 Commodity Delivery

The energy, or fuel, consumed for transport delivery of feed commodities depends upon the vehicle type, fuel used, fuel efficiency, loading efficiency and distance travelled. Diesel powered vehicles are mainly used for the transport of commodities.

Vehicle loading efficiency can vary greatly between commodity types, with straws and roughages being volume limited and grains and molasses being mass limited. Photograph 2 illustrates a semi trailer unloading grain.

Photograph 2 – Semi trailer unloading grain commodity.

4.2.3 Manure Removal

Removal of manure off-farm is also an indirect energy consumer. This process may be undertaken by the feedlot operator or by independent contractors. The energy efficiency of manure transport depends upon the truck type and fuel efficiency, the distance travelled and the volume and dry matter content of the manure. Stockpiling of manure pre-transport, either in the pen or in a designated stockpile area, reduces its moisture content and thus the volume of manure for transportation. Photograph 3 illustrates a typical manure removal operation. However, no data was collected in this project on this component.

Photograph 3 – Manure removal operation

4.3 Direct Sources

Feedlot operations consist of a number of synchronised and interactive components. Energy is used for the provision of water and feed to the livestock, waste management (including pen cleaning, manure treatment and effluent disposal) and the administration and operation of the facility.

4.3.1 Feed Storage and Processing

Feed storage and processing consists of a composite of simple components and processes. The major components may include storage structures, handling equipment, grain processing and feed mixing operations. Whilst many of the components are interactive, component design, selection and maintenance can influence the overall energy efficiency of a feed storage and processing system. Electric motors and mobile equipment are commonly used as the power sources. Photograph 4 illustrates a typical grain storage system.

Photograph 4 – Typical grain storage system

Feed processing methods are designed to improve the starch availability of grains, which in turn improves digestion and feed efficiency (Sweeten 1990). Various processing methods are used to produce a physical or chemical change in the grain. Some of the processing methods used in Australian feedlots include:

- Dry-rolling, grinding
- Steam flaking
- Reconstitution.

Individual feed processing equipment may include boilers for heat/steam generation and/or hammermills and roller mills for grinding or rolling. These processes are described in detail in other works (Holcomb & Hollis Klett 1994; Sweeten 1990). Photograph 5 illustrates a typical steam flaking grain processing system.

In studies in North America, feed processing has been identified as the largest single consumer of energy. Sweeten and McDonald (1979) found that steam flaking required in the order of 1010 cubic feet (28.6 kL) of natural gas and 60 kWh of electricity per head of feedlot capacity. This equates to approximately 1065 MJ of natural gas energy and 221 MJ of electricity consumption per head per year. Sweeten et al. (1986) undertook a similar survey of Texas feedyards in 1985 and for steam flaking found similar natural gas energy consumption and slightly higher electricity consumption of 274 MJ per head per day.

Lipper et al. (1976) found that feed processing accounted for approximately 56.7% of the total energy use in Kansas feedlots. However, the USDA estimated the energy use for feed processing and distribution accounted for 39.9% of the total energy (Sweeten 1990). This work also found lower consumption of natural gas and electricity and hence probably does not reflect steam flaking, dry rolling or dry heating of grain. It would appear to be more reflective of self mixing trucks using whole grain rations (Sweeten 1990). Steam flaking is the most energy intensive grain processing alternative (Schake et al. 1981).

Photograph 5 – Typical grain storage and steam flaking grain processing system

4.3.2 Feed Delivery/Feedlot Area

Front end loaders for feed mixing/load out and trucks are used to deliver feed from the feedmill to the feed bunks. The energy efficiency of this operation depends upon the type of machine, loaded weight, travel speed and fuel efficiency. Diesel powered vehicles are mainly used for the delivery of rations.

Other types of equipment including earthmoving equipment, tractors, light commercial vehicles and motorbikes are used for general feedlot operations. This may include feed alley and road maintenance, watering roads, slashing, cattle management, general travel around the feedlot etc. This equipment may use diesel or petrol fuel depending on the vehicle type. Photograph 6 illustrates a road watering operation.

Photograph 6 – Road watering operation

Energy used per ton of feed material delivered also depends upon haul distance, materials bulk density and engine idle time (Sweeten 1990). Lipper et al. (1976) estimated average energy used by Kansas feedlots for feed handling was approximately 16% of the total energy usage of the feedlot.

Paine, Teter and Guyer (n.d) suggest that careful feedlot layout design can result in 25% less travel with a subsequent 6-10% reduction in annual operating costs. Photograph 7 illustrates a typical feed delivery operation.

Photograph 7 – Typical feed delivery operation

4.3.3 Waste Management

Pen cleaning and the storage and reuse of manure uses energy. Feedlots use earthmoving equipment and tractors for collecting and loading manure, pen maintenance (including placing soil backfill to repair the feedlot surface), bunk cleaning and general maintenance. Wheeled loaders, graders, bobcats and tractors of various sizes are commonly used for these purposes. This equipment is relatively energy inefficient. Heavy equipment will mainly use diesel engines, with lighter equipment using petrol engines. Photograph 8 illustrates pen cleaning with box scraper. The volume of manure for transport is linked to the ration energy density, storage and handling. Increasing the percentage of roughage in a ration increases intake and decreases digestibility, thus increasing manure quantity.

Lipper et al. (1976) estimated that energy use for waste removal in Kansas feedlots was approximately 4% of the total energy usage.

Photograph 8 – Pen cleaning

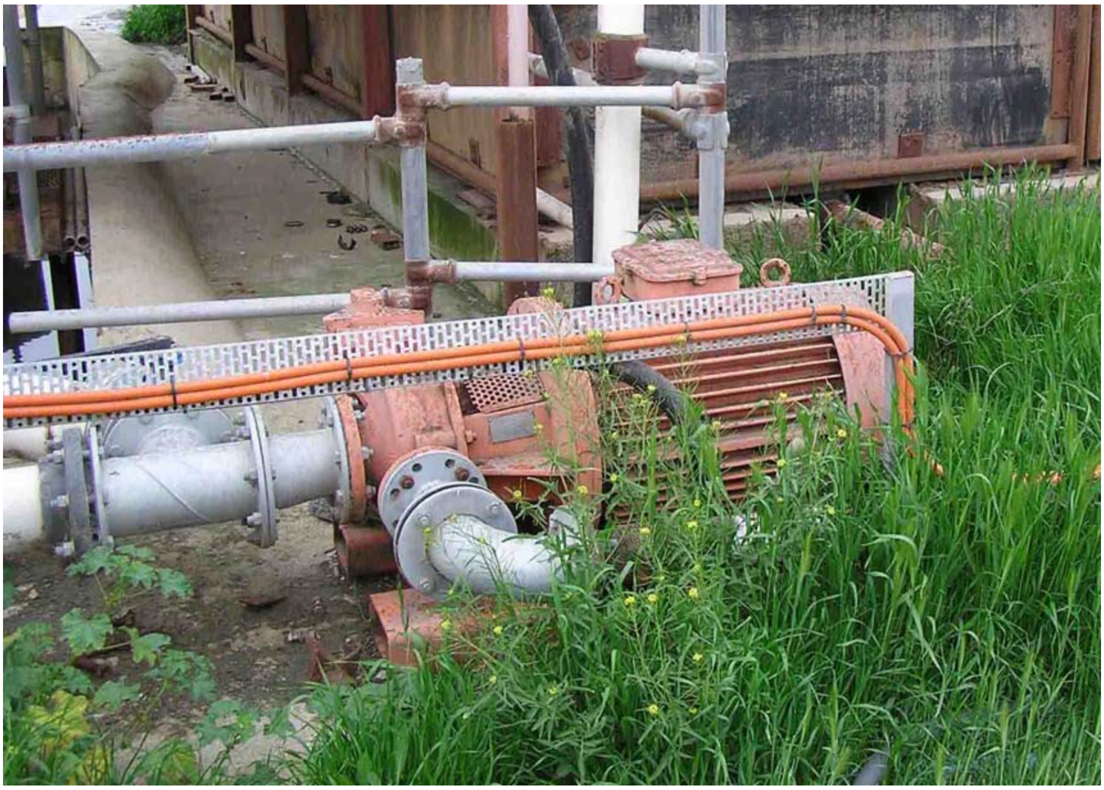
4.3.4 Water Supply

The energy used to maintain the water supply of a feedlot occurs mainly through pumping of drinking water and depends upon:

1) Total volume pumped (Litres).
2) Total dynamic head (vertical lift + friction losses + pressure at downstream end) (m).
3) Efficiency of the pumping plant (%).

The total water requirement is discussed in the Part A report. It is relatively fixed, based on the required daily drinking water supply and losses from evaporation and leaks in the distribution system. The total dynamic head directly affects energy requirements. Photograph 9 illustrates a typical electric water supply pumping system.

In their study, Lipper et al. (1976) found that maintaining the water requirements in a Kansas feedlot accounted for about 2.5% of the total energy usage. The USDA also estimated the percentage of energy used at feedlots and found that water supply consumed approximately 16.8% of the total energy usage (Sweeten 1990).



Photograph 9 – Water supply pump

4.3.5 Administration

Energy plays a vital role in the administration and operation of feedlots. Office facilities use energy for many purposes including heating and cooling, lighting, office equipment (computers, faxes, photocopiers etc) and staff amenities (refrigeration and cooking).

Lipper et al. (1976) reported that administration consumed approximately 5.6% of the total energy requirement of Kansas feedlots. Increased heating costs in winter may be a plausible explanation for this high percentage use.

4.3.6 Effluent Irrigation

The application of effluent to land areas requires energy for pumping and is dependent on:

1) Total volume pumped (Litres).
2) Total dynamic head (vertical lift + friction losses + pressure at downstream end).
3) Efficiency of the pumping plant (%).

Various types of irrigation systems are used, including travelling sprinklers, centre pivots and lateral moves. Photograph 10 illustrates a centre pivot irrigation system.

Photograph 10 – Centre Pivot irrigator

4.3.7 Farming Activities

Feedlots utilise various equipment including tractors, planting/harvesting equipment, light commercial vehicles and motorbikes for farming operations. This may include slashing, general travel around the farm, planting and harvesting crops etc. This equipment may use diesel or petrol fuel depending on the vehicle type. Some of the activities listed above such as planting and harvesting crops fall outside the boundary of the sub-system for the feedlot sector. However, it was difficult to partition these activities from activities used within the sub-system.

5 Literature Review - Greenhouse Gas Emissions

5.1 Introduction

The term emissions, in relation to greenhouse gases, is commonly defined as the release of GHG into the atmosphere. This covers direct releases of greenhouse gas emissions (Scope 1 emissions), and indirect releases of GHG from the consumption of purchased electricity, heat or steam (Scope 2 emissions) and other indirect emissions generated in the wider community as a consequence of a facility's activities (Scope 3 emissions).

There are three potential direct releases of GHG emissions (Scope 1 emissions) from a feedlot production system. They are the livestock themselves, the livestock waste during storage, treatment and utilization, and those resulting from the use of energy as described in Section 4.

The National Greenhouse Gas Inventory Committee (NGGIC 2002) estimated the emissions from intensive livestock production. Table 1 shows the relative breakdown between dairy, beef feedlots and piggery production systems. The livestock sectors are likely to expand in future years with strong growth currently occurring in the feedlot sector. The feedlot industry in Australia is the highest emitter of the animal intensive industries, currently around 3.5% of livestock emissions and about 0.44% of the national GHG emissions in 2002. The NGGIC estimation methodology does not account for emissions resulting from the use of energy, i.e. The estimates do not include all Scope 1 emissions. .

The Australian livestock subsector released 67.6 Mt CO_2-equivalents in 2002, making it the nation's largest source of agricultural GHG emissions (NGGIC 2002). The bulk of emissions are the non-carbon dioxide gases, methane and nitrous oxide. These two GHGs have a global warming potential 21 times (methane) and 310 times (nitrous oxide) that of carbon dioxide.

Emissions from agricultural livestock production are generally calculated by multiplying estimates of activity levels (such as cattle numbers, diet composition and manure production) by emission factors drawn from the NGGI. Methane from ruminants is responsible for one tonne in every seven of Australia's greenhouse emissions when measured as carbon dioxide equivalents. Since this is twice as high as the OECD average, it is a serious issue in national greenhouse policy.

The principle GHG arising from agricultural livestock production is enteric methane liberated from the anaerobic microbial fermentation of feedstuffs in the gut (95%). A small quantity of methane (3%) and nitrous oxide (N_2O) (2%) is released from degradation of faeces and urine. The contribution of N_2O is small relative to some developed countries and reflects differences in both manure management and inventory procedures for the Australian livestock industries. Of the 23.96 million beef cattle in Australia in June 2004, 23.3 million were extensively grazed and 666,000 in feedlots (Australian Bureau of Statistics 2004). The manure management portion of the GHG inventory only includes GHG emissions from the managed manures and effluent derived from the intensive livestock industries. The emissions from manure in extensively grazed operations are not credited in the inventory.

The total emissions from the feedlot production system represent 3.5% of total livestock emissions. The breakdown of these emissions is approximately enteric methane (64%), methane from manure (1%) and nitrous oxide from manure (35%).

Table 1 – Annual Emissions from intensive livestock production (excluding land clearing). (NGGIC 2002)

Sector	Methane (CH_4) Mt CO_2-e		Nitrous Oxide (NO_2) Mt CO2-e	Total emissions Mt CO_2-e	Total manure emissions Mt CO_2-e	% of total livestock emissions
	Enteric	Waste management	Waste management			
Dairy	7.5	0.6	0.01	8.1	0.61	11.9
Beef	39.3	-	-	39.3	-	58.2
Feedlot	1.5	0.02	0.8	2.3	0.82	3.5
Pigs	0.09	1.36	0.03	1.5	1.39	2.2
TOTAL	48.39	1.98	0.84	51.3	2.82	75.8

Note: This data is an average of 2001 and 2002 estimates.

Emission estimates from livestock sectors involves the collection and analysis of data based on many assumptions and simplifications. The Australian agriculture methodology contains both country specific and the Intergovernmental Panel on Climate Change (IPCC 1997) default methodologies and emission factors. The agriculture inventory is compiled on a state-by-state basis to reduce errors associated with averaging input data across areas with large physical and management differences.

Differences in cattle management, numbers, duration of daily feeding, dietary composition and climatic conditions affecting animal and microbial populations in manure may produce significant deviations between the NGGI estimates and actual GHG emissions from Australian feedlots.

In response to the potential environmental impact of intensive livestock systems, regulatory agencies and industry bodies have developed various environmental guidelines for each industry sector (Skerman 2000). For the most part, GHG emissions have not been regarded as a major issue for these industries (in comparison with the other environmental impacts) and, hence, most current guidelines make little or no reference to management of GHG emissions.

In the past, waste management research for Australian intensive livestock industries has focused on the current issues (odour, water pollution, soil degradation). Overseas work has been similar although Europe has included ammonia emissions. Comparatively little work has been done on GHG emissions but this is rapidly changing. As a result of this lack of emphasis on GHG in waste management for intensive livestock, there have been few research papers on GHG emissions from manure decomposition in Australia and no audits of emissions from stationary and transport energy usage for these industries. Our understanding of the best methods to reduce GHG emissions from intensive livestock waste management systems in Australia is slowly progressing and will improve substantially in future years.

Energy use is an integral part of a feedlot production system and GHG emissions from energy usage can be grouped into direct (Scope 1) and indirect (Scope 2 and Scope 3) emissions. Direct emissions are produced from sources within the boundary of the facility. In feedlots these emissions mainly arise from the following activities:

- Production of energy, heat, steam and electricity, including carbon dioxide and products of incomplete combustion (methane and nitrous oxide). For example production of energy for feed processing systems.
- Transportation of materials, products, waste and people. For example, use of mobile combustion sources such as feed preparation and delivery vehicles, manure handling and disposal vehicles, cars and motorbikes.
- Fugitive emissions: intentional or unintentional GHG releases. For example leaks from gas storages, pipes and seals.

Indirect emissions (Scope 2 and Scope 3) include those emissions generated in the wider economy because of the feedlot's activities (particularly from its demand for goods and services) but which are physically produced by the activities of another organisation. The most important category of indirect emissions results from electricity usage (Scope 2). Other examples of indirect emissions resulting from a feedlot's activities are the emission implications of livestock transport (Scope 3) to and from the facility or from contracting/outsourcing of activities.

The feedlot sector needs to be proactive to develop mechanisms that limit GHG emissions and adapt to climate change impacts in a way that minimises any dislocation and costs while at the same time make the most of any commercial opportunities.

Estimating the GHG emissions which result from the livestock themselves, the livestock waste and those resulting from energy use will now be discussed.

5.2 Emissions from Livestock and Waste Management

Emissions from livestock can be broken into direct methane emissions to the atmosphere (enteric methane) and methane and nitrous oxide emissions resulting from the breakdown of organic matter during manure storage, treatment and handling.

5.2.1 Enteric Methane – Basic Principles

Methane is produced in the digestive tract of ruminant livestock by microorganisms during anaerobic fermentation of the soluble and structural carbohydrates contained in the diet. Methane production is an integral part of feed digestion. It is greatly influenced by the nutritional management of livestock and reflects the quality and balance of nutrients, energy and protein in the diet. Methane emissions from ruminant livestock typically represent a loss of 5.5-6.5% of gross energy intake (Johnson and Johnson 1995).

The process of enteric fermentation, and hence methane production, refers to the microbial fermentation of animal feed under anaerobic conditions in the rumen (first-stomach). Undigested residues reaching the hindgut (colon and caecum) are subjected to further fermentation.

This process is illustrated in Figure 3. The numbers in the diagram refer to the various stages of converting feed to nutrients that can be used by the animal. In brief, feed enters the rumen where it is fermented to volatile fatty acids and methane by microorganisms (1). Volatile fatty acids are the end products of fermentation, and, once absorbed into the blood are the major energy (glucose) precursor for ruminants. Methane is primarily removed from the rumen through the mouth (eructation) (2). However, a small proportion is also absorbed into the blood and released through the lungs (McCrabb 2005).

The fermentation process is coupled with microbial growth. This growth and subsequent production of the microbial cell proteins form the major source of protein for ruminant livestock (3). Some proteins which are not fermented in the rumen by microorganisms pass through the rumen and are directly absorbed in the small intestine.

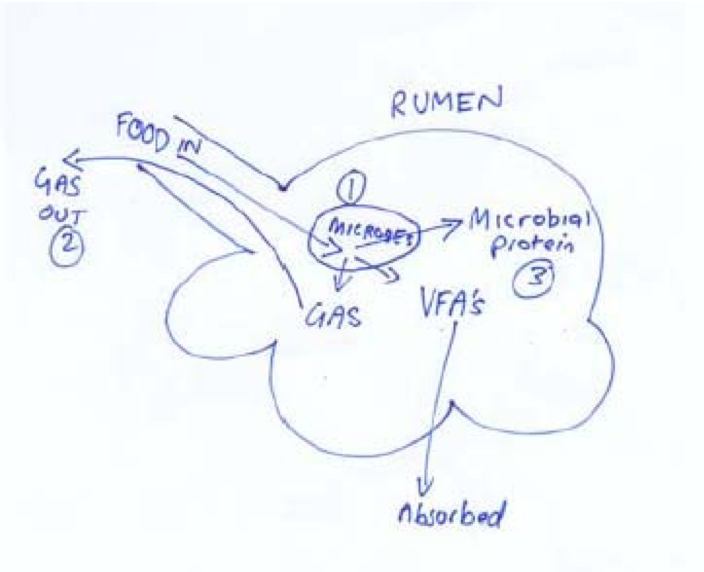


Figure 3 – Feed digestion by microorganisms in the forestomach of ruminant livestock (McCrabb 2005).

The efficiency of fermentation in the rumen depends on the diversity, size and activity of the microbial population in the rumen, which in turn is influenced primarily by diet. For example, under intensive lot-fed conditions rumen efficiency will vary depending upon the composition and variety of the diet. Bacteria are the principal microorganisms that ferment animal feed and the types of bacteria present are dietary related. The types of bacteria also determine the composition of the volatile fatty acids produced and the level of methane production. Methane production is dependant on (a) the level of intake and quality of the diet and (b) the percentage of this energy that is converted to methane (Hegarty 2001). This is basically how emissions from livestock are calculated by the NGGI. Feed intake can vary considerably and depends upon the weight of the animal and its level of productivity.

In contrast to forages consumed by grazing animals, the lot-fed diet offers minimal resistance to the rumen microbes and requires little cud-chewing before passing from the rumen to the intestines. Consequently, intake of the feedlot diet is unlikely to be limited by either rumen capacity or the properties of the feed. Rather, it is constrained by the animal's nutrient requirement. This nutrient requirement is principally a function of the animal's liveweight and state of maturity (Hegarty 2001).

Enteric methane is a waste gas of production and hence the more efficient the production system, the less methane is produced. Feedlots are more efficient at producing meat from feed and therefore will have lower emissions per kilogram HSCW than extensively grazed livestock. In reality, about 80 percent of the methane is produced during feed metabolism and released through the mouth as the animal belches (McGinn 2004).

Data on methane emissions from livestock in Australia are available from a limited number of studies. For many years, data were only available for animals kept in respiration chambers (airtight chambers that allow measurement of material and energy inputs and outputs, including gas exchange). Recently, new methods allow direct measurement of methane output from extensively grazed animals in the field. However, to date, there are insufficient data from these field experiments to derive relationships from which broader predictions of methane emissions could be made (Hegarty 2001).

Few studies have been undertaken on lot-fed cattle. Harper et al. (1999) investigated methane emissions from cattle grazed on pasture with the same cattle fed on a highly digestible, high-grain diet under simulated feedlot conditions. They found that the cattle produced 0.23 kg methane/head/day and 0.066 kg methane/head/day when fed on pasture and on high-grain diets, respectively. This corresponded to a conversion range of 7.7% to 8.4% and 1.9% to 2.2% of gross energy into methane for pasture and high-grain diets, respectively.

Phetteplace et al. (2001) estimated the greenhouse gas emissions from US beef cattle operations based on IPCC methodology. They estimated the enteric methane in feedlot cattle from gross energy intake and found it to be 1.3 kg CO_2-e per liveweight gain.

McGinn et al (2008) measured CH4 emission from an Australian feedlot and Canadian feedlot in 2007. Their measured methane emissions integrates the emissions over the entire feedlot and that includes both enteric and manure CH4 emissions. McGinn et al (2008) measured methane emissions of 166 g CH_4 /animal.day.

There are a number of reasons why feedlot diets with extremely high starch contents cause low enteric methane emission rates and these principally relate to the fermentation pattern and organisms in the rumen of lotfed cattle as outlined below.

Starch is readily fermented to propionate by rumen microbes and the production of propionate uses hydrogen. Hydrogen is also required in the production of methane, so the use of some hydrogen for propionate production means that it is not available for methane production. Correspondingly, the major source of hydrogen in the rumen is fermentation to acetate, and production of acetate is relatively less important in starch fermentation than in forage fermentation. Consequently, the balance between hydrogen producing reactions (acetate production) and hydrogen using reactions (propionate production) leads to a net reduction in hydrogen availability for the methanogens in the rumen of feedlot compared to pasture finished ruminants (Hegarty 1999).

Reducing methane production translates into improved feed efficiency. Mitigating methane loss has both long-term environmental and short-term economic benefits. However, it should be recognised that when reducing ruminal methane production, methanogenesis is normally central to continued fermentative digestion of feed. The ruminant depends on fermentation for other microbial products on which the animal itself lives, such as microbial protein and volatile fatty acids. Methane producing organisms normally remove hydrogen gas from the rumen by converting it to methane. Hydrogen is a waste product of fermentation and if hydrogen accumulates, rumen digestion is suppressed (Hegarty 2001). The goal in addressing livestock methane emissions then, is not simply stopping methane emissions, but rather, redirecting hydrogen into more beneficial pathways (Hegarty 1999).

Dietary changes can affect methane emissions by: decreasing the fermentation of organic matter in the rumen; shifting the site of digestion from the rumen to the intestines; or by inhibiting methanogenesis by rumen bacteria (Johnson and Johnson 1995). Approaches to alter the microbial ecology of the rumen for the purpose of reducing daily methane production, without requiring a decline in feed intake, are varied.

Dietary composition and ration changes affect the levels of enteric methane produced. The addition of ingredients to increase the energy density of diets allows for the incorporation of more forages and less grain into diets without compromising energy density (Boadi et al. 2004). Boadi et al. (2004) found that replacing 50% of the cereal grain in a typical feedlot diet with forage and oilseed produced lower enteric methane emissions per unit gain compared to traditional high concentrate diets.

The addition of dietary fats to increase the energy density of high forage diets has depressed enteric methane production in short-term in-vitro studies. A comparison of the efficacy of a range of oils has identified coconut oil as being most effective (Dong et al. 1997). It is the medium chain fatty acids, which cause the greatest reduction in methane production (Dohme et al. 2000) and also the methanogen population (Dong et al. 1997). A reduced effect of medium chain fatty acids on high-fibre content diets indicates that the practical application of this may be limited to feedlots (Hegarty 1999).

In practice, there is limited practical scope for increasing the energy content of feedlot diets to reduce daily emissions using cereal grains due to the increased risk of rumen acidosis (a nutritional disease) and the absence of higher energy feedstuffs. Inclusion of selected oils provides a safer way of increasing the energy content of feedlot diets which could reasonably be expected to further reduce daily methane emissions (Hegarty 2001).

Methanogens and methane production are also inhibited by acidic conditions and the rumen of animals consuming a high-starch feedlot diet is typically more acidic than that of forage fed ruminants. There may well be other as yet unidentified inhibitors of methanogenesis in the rumen of feedlot animals. Many lactic acid bacteria also naturally produce antibiotic-like substances called bacteriocins and these may possibly also contribute to the effect of higher energy feedlot diets lowering the daily enteric methane release (Hegarty 1999).

It is widely acknowledged that including antibiotic growth promoters in livestock diets increases their growth rates (Page 2003). Changes in fermentation dynamics in the rumen when ionophores (e.g.

Lasalocid, Monensin, Narasin and Salinomycin) are added to the diet improve the efficiency of energy capture and utilisation of dietary nitrogen. The result of this interaction with the organisms of the gut is improved digestion, metabolism and absorption of an array of essential nutrients, including carbohydrates, proteins, amino acids, minerals and vitamins. Ionophores also have additional benefits in attenuating certain cattle digestive disorders, including bloat, an excess production of stable foam in the rumen; and acidosis, an accumulation of lactic acid and/or volatile fatty acids (VFA) in the rumen due to an increase of rapidly fermentable carbohydrates (grain) in the diet (Page 2003).

Ionophores have the potential to decrease the production of methane since they promote a shift in the microbial population of the rumen from gram-positive to gram-negative bacteria. Bacteria that produce lactic, acetic, butyric, and formic acids and hydrogen as main end products are susceptible to ionophores, whereas succinic and propionic acid-producing bacteria are resistant (Tedeschi et al. 2003).

The use of ionophores in cattle diets has been proposed as a mitigation strategy for enteric methane emissions. Literature supporting this strategy is limited. Much of the evidence on the ability of ionophores to reduce methane output per unit of feed fermented comes from in-vitro studies.

In their review, Tedeschi et al. (1997) found that they generally reduce methane output but the percentage inhibition shows a wide range (4-31%) and is related to ionophore type and dose rate. There is some evidence of an adaptation to ionophores, such that the methane reduction per unit of feed is only temporary and typically not maintained for long periods (Johnson and Johnson, 1995).

McGinn et al. (2004) measured enteric methane emissions from Holstein steers fed a diet containing 75% barley silage and 19% steam flaked barley and found that the addition of monensin to the diet reduced methane emissions by 9%.

Immunisation to improve animal performance and directly reduce methane emissions by invoking an immume response in the rumen has been shown in sheep. Development of a vaccination strategy to reduce rumen methanogensis is in progress and claims, based on animal trials in sheep, that it will reduce methane production in sheep and cattle by 11-23% and, in addition, increase productivity. The vaccine is still at the development stage and it not likely to be available for evaluation purposes until 2005 for cattle (Hegarty 2001).

The NGGIC (2002) consider that the most appropriate method for estimating enteric methane emissions from feedlot cattle in Australia is the approach devised by Moe and Tyrrell (1979). They devised equations for predicting methane emissions from dairy cattle fed diets consisting mostly of high digestibility grains and concentrates and high quality forages. This approach requires the estimation of gross energy intake and then calculates the proportion of this energy that is converted into methane based on the digestibility at maintenance of the feed energy and the level of feed intake relative to that required for maintenance.

To determine methane emissions, the NGGIC (2004) uses equations relating production to the intake of three components of the dietary carbohydrate. These are: soluble residue, hemicellulose and cellulose.

The NGGIC (2004) equation to predict daily methane yields, Y (MJ CH_4/head/day) is:

$Y = 3.406 + 0.510 \times SR + 1.736 \times H + 2.648 \times C$ (Eqn 1)

Where:

SR = intake of soluble residue (kg/day)
H = intake of hemicellulose (kg/day)
C = intake of cellulose (kg/day)

Each of SR, H and C is calculated from the total intake of the animal, the proportion of the diet of each class of animal that is grass, legume, grain (including molasses) and other concentrates and the soluble residue, hemicellulose and cellulose fractions of each of these components.

For example:

SR = (I x Pgrain x SRgrain) + (I x Pconc x SRconc) + (I x Pgrass x SRgrass) + (I x Plegume x SRlegume)

H = (I x Pgrain x Hgrain) + (I x Pconc x Hconc) + (I x Pgrass x Hgrass) +(I x Plegume x Hlegume)

C = (I x Pgrain x Cgrain) + (I x Pconc x Cconc) + (I x Pgrass x Cgrass) + (I x Plegume x Clegume)

Where:
I = intake (kg/day)
Pgrain = proportion of grains in feed
Pconc = proportion of concentrates in feed
Pgrass = proportion of grasses in feed
Plegume = proportion of legumes in feed
SRgrain = soluble residue content of grain
SRconc = soluble residue content of other concentrates
SRgrass = soluble residue content of grasses
SRlegume = soluble residue content of legumes
Hgrain = hemicellulose content of grain
Hconc = hemicellulose content of concentrates
Hgrass = hemicellulose content of grasses
Hlegume = hemicellulose content of legumes
Cgrain = cellulose content of grain
Cconc = cellulose content of concentrates
Cgrass = cellulose content of grasses
Clegume = cellulose content of legumes

The total daily production of methane, M (kg methane/head/day) is thus:

$M = Y / F$ (Eqn 2)

Where:

F = 55.22 MJ/kg CH_4

Methane production (E) for feedlot cattle can then be calculated as:

$$E = 365 \times N \times M \times 10^{-6} \qquad \text{(Eqn 3)}$$

Where:
N = numbers of feedlot cattle on hand as an annual equivalent in each class.
M = methane production (kg/head/day)

5.2.2 Emissions from Waste Handling, Storage and Utilisation

The primary by-product of feedlot production is manure harvested from the pen floors. Carcasses from a small number of mortalities are another by-product. Incorrectly handled, these by-products have the potential to adversely affect the environment through reduced community amenity (primarily because of odour and dust), water pollution and soil degradation. Sound waste treatment / management systems are used at feedlots to prevent these problems.

Manure (faeces and urine) contains water (H_2O), complex carbohydrates, nutrients (nitrogen (N), phosphorous (P) and potassium (K)), trace elements, salts and energy. Most fresh manures have a moisture content of 80% to 90%. Other feedlot wastes include spilt or spoilt feed and carcasses of dead livestock. The complex carbohydrates in these wastes contain carbon (C), hydrogen (H) and oxygen (O) in various combinations. In feedlot manure, these carbohydrates are in the form of various starches, sugars, cellulose, hemicellulose, lignin and other compounds.

Decomposition of manure releases the GHGs: methane (CH_4), carbon dioxide (CO_2) and nitrous oxide (N_2O). The amount of methane, carbon dioxide and nitrous oxide released depends upon the quantity and characteristics of carbohydrates in manure. Additional gases are emitted during decomposition of manure, including ammonia and nitrogen oxides. The release of these gases contributes to odour releases and is an indirect source of nitrous oxide.

Factors influencing GHG emissions from manure are: moisture content, oxygen content and substrate material. These three vary widely depending on feedlot location (climate, rainfall), feedlot design (shade, drainage) and type of manure management.

The type of manure management system used also influences the type and extent of GHG emissions. Individual components of management systems include pen cleaning, mounding manure in pens, stockpiling manure, composting manure, sedimentation basins and holding ponds. Some GHG is emitted from every individual component of the waste management system.

5.2.2.1 Methane Emissions

Methane can be emitted from livestock manure in two main ways. Firstly through the direct release of methane that becomes trapped in the faeces as it passes through the lower intestine of the animals. Secondly, through the fermentation of the organic matter (volatile solids (VS)) remaining in anaerobic microsites in the faeces and adjacent soil. Although methane entrapped in faeces whilst in the intestinal tract would diffuse out following deposition this methane is accounted for in the enteric emission calculations (NGGIC 2002).

The rate of methane emissions depends upon the volatile solids content of the manure and the manure management system. The estimation of methane emissions from manure is based on an estimate of the volatile solids content of manure taking into consideration the emissions potential (B_o) and MCF. Casada and Safley (1990) developed a method for estimating methane releases from manure by making certain assumptions about the percentage of ultimate methane yield (B_o in m^3 CH_4/kg VS) that could be expected by different manure management systems. B_o is the ultimate methane yield of an anaerobically digested material. This is sometimes referred to as biological methane potential (BMP). The percentage of B_o that is achieved by different manure management systems is the MCF. B_o varies with animal species and diet. Table 2 gives 'standard' values of B_o for various livestock types but it must be emphasised that these are averages and can vary substantially depending on diet. In general, ruminants have a low B_o for their manure presumably because most of the methane potential is extracted as enteric methane during fermentation in the rumen. Ruminant manures have a higher proportion of remaining carbohydrates that are difficult to break down such as cellulose and lignin.

Table 2 – Methane-production potential, B_o, for different intensive livestock

Livestock Category	Sub-group	Liveweight (kg)	Manure (kg DM/hd/day)	VS (kg/hd/day)	B_o (m^3 CH_4/kg VS)
Dairy Cattle	Mature females	500	3.77	3.47	0.24
Beef Cattle	Mature females	400	3.91	3.60	0.17
	Mature Males	450	3.38	3.11	0.17
	Young	200	2.41	2.21	0.17
Pigs	Average	82	0.51	0.43	0.45

(taken from IPCC (1997) for Oceania and developed countries)

The MCF provides an estimate of the portion of the methane-producing potential of waste that is achieved (IPCC 1997). Different waste management systems and climatic conditions affect the methane-producing potential of waste. Manure managed as a liquid under hot conditions has higher methane formation and emissions and hence a high MCF value. Manure managed as dry material in cold climates does not readily produce methane and consequently has a lower MCF.

Depending on the moisture content of the manure some breakdown occurs on the pen surface. Safley et al. (1992) found a MCF of approximately 10% in dry open lot situations, whereas Steed and Hashimoto (1995) found that the MCF of dairy cow manure ranged from 2% at 30°C to 0.0% at 10°C. Steed and Hashimoto (1995) also found the MCF resulting from wet anaerobic manure ranged from 65.5% at 30°C to 45.7% at 20°C to 0.0% at 10°C.

Steed and Hashimoto (1995) demonstrated the effect of manure temperature on anaerobic process and the amount of methane produced from dairy cow manure. They determined the MCF for different waste management systems at different manure temperatures. Figure 4 clearly shows that, as temperature declines, the amount of methane produced by any waste treatment system declines to zero at and below 10°C. Most Australian intensive livestock operations are located in areas where the climate is warm to hot. During dry weather, Australian pen surfaces are reasonably dry and a low MCF would apply. However, for a few days after heavy rain, the pen surface can be close to a liquid slurry. During this period, a high MCF would apply. There is no data available calculating MCF's that would apply to Australian feedlot surfaces over a range of climates (rainfall and temperature).

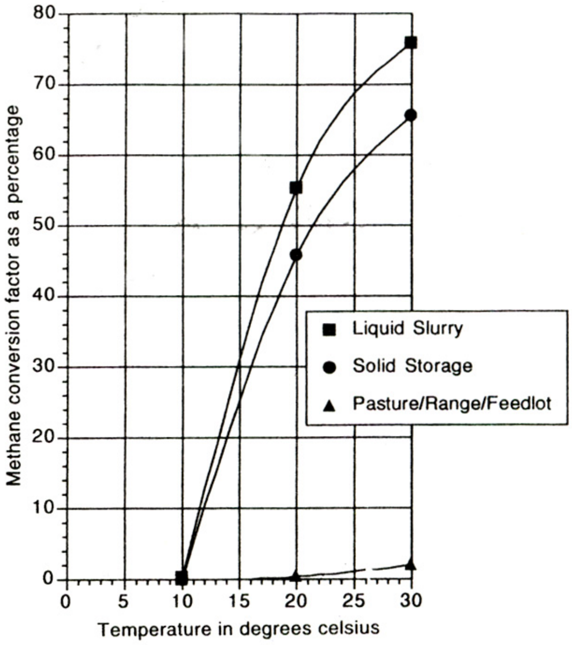


Figure 4 – Methane conversion factors (MCF) for various waste management systems

In the methodology used by the NGGIC, the IPCC (1997) default values for drylot MCF's are 1%, 1.5% and 5% in cold, temperate and warm climates respectively. This assumes that a dry packing arrangement is common in most feedlots in Australia and therefore is likely to result in only a small fraction of the potential methane emissions being generated (IPCC 1997). Thus, no consideration is given for anaerobic (wet pen) conditions in feedlot pens following rainfall.

In the methodology used by the NGGIC, no emissions are estimated from feedlot holding ponds even though most feedlots have large holding ponds that operate in an anaerobic environment.

The NGGIC (2002) method of estimating emissions from manure is as follows.

Volatile solid production for beef cattle in feedlots (VS kg/head/day) can be estimated using equation 4.

$$VS = I \times (1 - DMD) \times (1 - A) \qquad \text{(Eqn 4)}$$

Where:

I = Dry matter intake.

DMD = digestibility expressed as a fraction (assumed to be 80%).

A = ash content expressed as a fraction (assumed to be 8% of faecal DM).

Volatile solids are calculated using standard figures for dry matter intake and ration digestibility. This is calculated using BEEFBAL (Queensland Department of Primary Industries and Fisheries 2005).

Methane production, M from the faeces (kg/head/day) is then calculated as:

$$M = VS \times B_o \times MCF \times \rho \qquad \text{(Eqn 5)}$$

Where:

B_o = emissions potential - 0.17m^3 CH_4/kg VS (IPCC 1997)

MCF = methane conversion factor - Drylot MCF values for ‘warm’ regions for Queensland and the Northern Territory (5%) and MCF values for ‘temperate’ regions for all other States (1.5%).

ρ = density of methane (0.662 kg/m^3)

The annual methane production from the faeces of Australian beef cattle in feedlots is calculated as:

$$E = 365 \times N \times M \times 10^{-6} \qquad \text{(Eqn 6)}$$

Where:
N = annual equivalent numbers of beef cattle on hand in feedlots
M = methane production (kg/head/day)

5.2.2.2 Nitrous Oxide Emissions

Significant amounts of nitrogen are deposited on the feedlot surface through urine and faeces. Nitrogen can be rapidly lost to the atmosphere through volatilisation resulting in higher carbon to nitrogen ratios, reduced fertiliser value and air quality concerns (see Part C report). Most research in Australia and overseas has focussed on ammonia emissions and techniques for minimisation. However, ammonia volatilisation does not account for all the nitrogen lost. Gaseous nitrogen losses from feedlots by other processes, such as biological denitrification, have not been widely investigated. (Woodbury et al. 2001).

Potential sources of nitrous oxide emissions occur during the storage and treatment of manure. Nitrous oxide can be emitted as a by-product from the conversion of nitrogenous compounds of ammoniacal nitrogen contained in the manure, to ammonia and nitrate. This occurs through the biological pathways of nitrification or denitrification. Nitrous oxide is predominantly given off when a material containing nitrates is wet but not saturated during the denitrification process. The amount of nitrogen excreted and the storage and treatment of manure impacts on the potential for emissions of nitrous oxide.

The NGGIC methodology for estimating emissions is based on the IPCC (1997) guidelines incorporating manure management systems that reflect Australian conditions. The key factors for the determination of the potential production of nitrous oxide are the amount of nitrogen excreted and the emission factor (Nitrous Oxide/N excreted) of the manure management system.

The NGGIC methodology for calculating the excretion of nitrogen from beef cattle calculates the crude protein input and storage and from these the output of nitrogen in the faeces and urine. The methodology for calculating the excretion of nitrogen from feedlot cattle makes use of the following algorithms to calculate crude protein input (CPI) and storage (NR) and from these the output of nitrogen in the faeces and urine.

The CPI (kg/head/day) of feedlot cattle is calculated by:

$$CPI = NI \times 6.25 \qquad \text{(Eqn 7)}$$

Where

NI = nitrogen intake (kg/day)
6.25 = factor for converting nitrogen into crude protein

NI is calculated from the total intake of the animals as the proportion of the diet that is grass, legume, grain (including molasses) and other concentrates and the nitrogen fraction of each of these components.

For example:

$$NI = (I \times P_{grain} \times N_{grain}) + (I \times P_{conc} \times N_{conc}) + (I \times P_{grass} \times N_{grass}) + (I \times P_{legume} \times N_{legume})$$

Where:
N_{grain} = nitrogen content of grain
N_{conc} = nitrogen content of other concentrates portion of the diet
N_{grass} = nitrogen content of grasses portion of the diet
N_{legume} = nitrogen content of legumes portion of the diet

The methodology for estimating nitrogen excretion in manure, F (kg/head/day) is based on the indigestible fraction of the undegraded protein from solid feed and the microbial crude protein plus the endogenous faecal protein. This methodology takes a mass balance approach where N output = N input - N storage. The total N output is then split into urinary and faecal components. The excretion values produced by this methodology are consistent with observed values (NGGIC 2002).

The nitrogen excreted in faeces (F kg/head/day) is calculated as:

$$F = \{0.3(CPI \times (1-[(DMD+10)/100])) + 0.105(ME \times I \times 0.008) + 0.0152 \times I\} / 6.25 \qquad \text{(Eqn 8)}$$

Where:

DMD = digestibility expressed as a percentage (assumed to be 80%)
ME = metabolisable energy (MJ/kg DM) is calculated:

$$ME = 0.1604 \times DMD - 1.037 \qquad \text{(Eqn 9)}$$

I = feed intake (kg/day)

The amount of nitrogen that is retained by the body, NR (kg/head/day) is calculated as the amount of nitrogen retained as body tissue such that:

$$NR = \{[0.212-0.008(L - 2) - \{(0.140-0.008(L - 2)) / (1+\exp(-6(Z - 0.4)))\}] \times (LWG \times 0.92)\}/6.25 \quad \text{--- (Eqn 10)}$$

Where:

L = Relative intake, which is feed intake divided by the intake require for maintenance.

Z = Relative size (liveweight/standard reference weight)

LWG = Liveweight gain

Nitrogen excreted in urine (U kg/head/day) is calculated by subtracting NR, F and dermal protein loss from the nitrogen intake such that:

$$U = (CPI / 6.25) - NR - F - [(1.1 \times 10^{-4} \times W^{0.75})/6.25] \quad \text{(Eqn 11)}$$

Where:

W = Liveweight

The total annual faecal (AF) and urinary (AU) nitrogen excreted is then calculated by:

$$AF = (N \times F \times 365) \times 10^{-6}$$

$$AU = (N \times U \times 365) \times 10^{-6}$$

Where:

F = Eqn 8
N = the annual equivalent number of feedlot cattle.
U= Eqn 11

The total emissions of nitrous oxide from the different manure management systems can then be calculated as follows:

$$\text{Faecal}_{MMS} = (AF \times MMS \times EF_{(MMS)} \times 44/28) \quad \text{(Eqn 12)}$$

$$\text{Urine}_{MMS} = (AU \times MMS \times EF_{(MMS)} \times 44/28) \quad \text{(Eqn 13)}$$

$$Total_{MMS} = (\text{Faecal}_{MMS} + \text{Urine}_{MMS}) \quad \text{(Eqn 14)}$$

Where:

MMS = the fraction of the annual nitrogen excreted (AU + AF) that is managed in the different manure management systems. It is assumed that with feedlot cattle all manure is dry packed (MMS = 4).

$EF_{(MMS)}$ = emission factor (N_2O-N kg/ N excreted) for the different manure management systems. Table 17 in Appendix A gives emission factors for different management systems.

44/28 = factor to convert elemental mass of N_2O to molecular mass.

As for volatile solids, the amount of nitrogen excreted per head per day can be estimated using mass balance models such as BEEFBAL (McGahan 2002). By entering typical animal characteristics, feed intakes, diet compositions and wastage rates, the model can estimate the nitrogen in the manure and waste feed.

5.2.2.3 Impact of manure management systems on GHG emissions

The type of manure management system and its individual components influences GHG emissions.

Stockpiling of manure may be required due to weather conditions or operational requirements preventing immediate application to land. In general, manure that has been recently removed from the pen surface contains over 50% moisture. When this manure is stockpiled, anaerobic conditions exist and these are generally disrupted during handling resulting in emissions of methane. Stockpiling provides potential reductions in bulk but may also allow the gaseous loss of nitrogen and an increase in ammonium concentration. This may lead to an increase in the emission of odourous gases.

Active composting of manure involves management of the manure stockpile to maintain adequate levels of aeration and moisture. During active composting, decomposition occurs aerobically and mainly carbon dioxide is emitted. From a sustainability viewpoint, active composting is becoming increasingly popular as a waste management option because it reduces the moisture content of the manure, thus reducing the mass of waste to be handled. It also concentrates most nutrients and kills pathogens and weed seeds. If managed correctly, the composted product is free of odours. Composted manure is also more friable and can be more evenly spread.

Hao et al. (2001) examined GHG emissions from the composting of feedlot manure and wheat straw. They found that in ‘passive’ windrows the emissions of carbon dioxide, nitrous oxide and methane were high during the first 30 days but declined to almost zero for the remainder of the study. Total GHG emissions in terms of carbon dioxide equivalent was 240.2 kg $C0_2$-e/Mg of manure with methane contributing 55%, nitrous oxide 14% and remainder from carbon dioxide. In contrast actively managed windrows emitted 401.4 kg CO_2-e/Mg in terms of carbon dioxide equivalents with 42% from methane, 14% from nitrous oxide and the remainder from carbon dioxide.

Composting releases GHGs to the environment. When actively aerated composting occurs manure decomposition is enhanced and carbon dioxide is the main gaseous emission. From an ecological perspective, this carbon dioxide does not contribute to the greenhouse effect because it is returning to its source reservoir in its original form. These characteristics distinguish it from the methane and nitrous oxide emissions.

Manure management systems that achieve low MCF values, minimal volatile solids content and nitrogen excretion while maintaining low Nitrous Oxide/N emission rates produce less greenhouse impacts. Optimising this combination will also provide economic and environmental gains through improved resource utilisation.

No studies under Australian conditions have assessed the breakdown of manure components. The fact that large amounts of nitrogen are lost during manure storage and handling is well known to the industry. The form in which the nitrogen is lost is not well known but it will likely become important to the industry in the future.

5.3 Emissions from Energy Usage

The Australian Greenhouse Office (2004) provides emission factors for calculating direct and indirect GHG emissions from energy usage. Emissions from fossil fuels are most appropriately defined in terms of carbon dioxide generated per unit of energy because:

- Carbon dioxide production is directly related to energy releases from a carbonaceous fuel.
- Energy content on a heating value basis is essentially independent of diluents such as ash, water and nitrogen.

Emission factors can be grouped into ‘point source emissions factor’ or a ‘full fuel cycle emissions factor’. According to the NGGIC the point-source emissions factor gives the quantity of a given GHG emitted per unit of energy, fuel etc., at the point of release of the emission. Combustion emissions occurring at the point of final fuel consumption (e.g. emissions from the combustion of fuel in vehicles) constitute point-source emissions.

Emissions from on-site waste disposal would also be calculated using a 'point source' emissions factor. A “full fuel cycle emissions factor” gives the quantity of GHG emissions emitted per unit of energy for the entire fuel production and consumption chain. As an example, in the case of electricity, the full fuel cycle emission factor includes the sum of the emissions generated at the point of combustion in the power station, the fugitive and energy emissions from the mining and production of the fuels used in the power station, and any subsequent losses in the transmission and distribution networks during the delivery of the electricity.

The Australian Greenhouse Office programs regularly require manufacturing and industrial organisations to consider the full impact impact of their activities - that is both upstream and downstream activities and direct and indirect emissions. For the purpose of energy related emissions, these consequences are captured through the use of ‘full fuel cycle emission factors’.

The emissions factors for calculating emissions cover both direct and some indirect emissions (with the exception of the use of transport fuels).

In line with the National Greenhouse challenge program, the following emission factors have been used for this work:

- Transport fuel emissions. Under the Greenhouse Challenge these reflect emissions for combustion of the fuel only.

- All other emissions from fuel and energy use (including electricity) are calculated using full fuel cycle emissions factors.
- Waste emissions are calculated on the basis of emissions on site and downstream disposal using consistent factors.

Emission factors are used to calculate GHG emissions by multiplying the factor (eg kg CO_2/GJ energy in petrol) with activity data (eg kilolitres x energy density of petrol used).

The method for estimating emissions in the energy sector calculates emissions from the combustion of fuels in stationary non-transport uses, transport uses and from the consumption of electricity. Emissions are generally expressed in tonnes of CO_2-equivalent (CO_2-e), which includes carbon dioxide as well as the global warming effect of the relatively small quantities of methane, nitrous oxides and perflurocarbons.

5.3.1 Stationary Energy Emissions (non-transport)

5.3.1.1 Fuel combustion emissions (excluding natural gas)

The following formula can be used to estimate GHG emissions from the combustion of each type of fuel used for non-transport purposes at a feedlot excluding natural gas (Australian Greenhouse Office, 2004).

GHG emissions (t CO_2-e) = Q x EC x EF/1000

Where:

Q is the quantity of fuel consumed in tonnes or thousands of litres.

EC is the energy content of fuel in GJ/tonne or GJ/kL.

EF is the relevant emission factor (Table 1, Fuel combustion emission factors (Stationary Energy), Australian Greenhouse Office 2004).

Most of the emissions occur at the point of final fuel combustion, that is, the point source emission factor. However, the broadest estimate of total emissions resulting from the use of the fuel includes those emissions associated with the production and transport of the fuel. Therefore the full fuel cycle emissions factor is used in each calculation. Separate calculations are needed for each fuel type.

5.3.1.2 Fuel combustion emissions (Natural gas)

The NGGIC separates the users of natural gas into small and large depending on the scale of use. Large or major users are those supplied at high pressure and with an annual usage of more than 100 000 GJ.

The estimates of emissions can be calculated using the following formula (NGGIC 2004):

GHG emissions (t CO_2-e) = Q x EF/1000

Where:

Q is the quantity of natural gas consumed and expressed in GJ.

EF is the relevant emission factor. (Table 2, Emissions from the consumption of natural gas, Australian Greenhouse Office 2004). The EF is dependent on location (state and territory) and whether the site is a small or large user. Most of the emissions occur at the point of final fuel combustion. However, the broadest estimate of total emissions from fuel usage includes those emissions associated with the production and transport of the fuel. Therefore, the full fuel cycle emissions factor is used in each calculation.

5.3.1.3 Fuel Combustion Emissions - Transport Fuels

The emissions associated with transport are mostly carbon dioxide, with small amounts of nitrous oxides and methane.

The following formula can be used to estimate GHG emissions from the combustion of fuels used for transport:

GHG emissions (t CO_2-e) = Q x EF

Where:

Q is the quantity of fuel in thousands of litres or energy equivalent in GJ.

EF is the relevant emission factor. EFs for combustion of fuels used for transport are reported in Table 3 Fuel Combustion Emission Factors (Transport Fuels), (Australian Greenhouse Office 2004) in both kg CO_2-e per GJ and kg CO_2-e per kL. Most of the emissions occur at the point of final fuel combustion, that is, the point source emission factor. For estimating emissions associated with transport fuels the point source emission factor is used.

5.3.1.4 Electricity End Use Emissions

GHG emissions associated with the quantity of electricity consumed in tonnes of CO_2-e may be calculated with the following equation (Australian Greenhouse Office 2004):

GHG emissions (t CO_2-e) = Q x EF

Where: Q is the electricity used expressed in kWh or GJ;

EFs for the consumption of electricity are state-based because electricity flows between states are significantly constrained by the capacity of the inter-state interconnectors (or in some cases there are no interconnections). The full fuel cycle emission factor is used. The full fuel cycle includes carbon dioxide, methane and nitrous oxide emissions from power stations and indirect combustion and fugitive emission from fuel production. The factors include average transmission and distribution losses in each state as well as interstate electricity flows.

6 Data Collection and Analysis

6.1 Data Survey

As part of the FLOT.328 project, a detailed survey of feedlot inputs and outputs was undertaken. The survey was conducted on-line.

For this report, the relevant data included:

1. Data on the number of incoming and outgoing cattle, intake and sale weights, dressing percentages and other parameters that allow HSCW gain to be estimated for two years (2002 & 2004).

- Data on mean distance travelled by incoming and outgoing cattle to allow calculation of indirect energy consumption for two years (2002 & 2004).
- Data on mean travel distance of individual commodities to the lot to allow calculation of indirect energy consumption for two years (2002 & 2004).
- Energy consumption (L/yr, kg/yr, KWh/yr) broken up by feed processing, feed delivery, water supply, administration, irrigation and other farming activities for two years (2002 & 2004).

Most feedlots were able to provide good-quality data on incoming and outgoing cattle numbers, production and total energy usage and where possible individual component energy usage. In addition, it was possible to estimate annual GHG emissions from indirect and direct energy usage and livestock.

Hence, it was possible to estimate total indirect and direct energy usage and GHG emissions in terms of HSCW gain (kg).

6.2 Sources of Energy Consumption

The survey indicated energy was used both indirectly and directly at feedlots. Activities using energy include:

- Transport of cattle from source.
- Transport of cattle to abattoir/sale.
- Delivery of commodities to feedlot.
- Feed processing/feed delivery to pens/manure management.
- Water supply.
- Administration.
- Irrigation.
- Other farming activities.

6.3 Data Analysis

Data input into the survey forms by lot feeders was entered into the Feedlot Systems Analysis Model (FSA Model) which was used to estimate various parameters and to undertake data quality checks. Where anomalous data were detected, the participating feedlot was contacted and the data was examined in more detail.

However, in some cases there still remained a mismatch between the mean number of cattle on hand estimated by the FSA model and that given in the survey. In most cases this was due to the yearly cattle number data and summary mean cattle on hand entered into the survey which does not capture monthly fluctuations. The following discussion outlines potential errors in the data.

Firstly, HSCW gain was calculated from the survey data of cattle numbers in, entry weight, total liveweight in, cattle numbers out, exit weight and total liveweight out and mortality numbers. Secondly, HSCW gain was estimated by the spreadsheet model from the model estimated number of cattle in, entry weight from survey and model estimated number of cattle out, exit weight from survey and mortality numbers from survey. In both cases, an estimate of dressing percentage in and out was required.

The mean number of cattle on hand on the 1st and last day of each survey year was required to be input into the survey. The average of this was used as the survey mean number of cattle on hand. This was compared with the FSA Model estimated mean number of cattle on hand and the difference presented in Figure 5 and Figure 6 from 2002 and 2004 respectively.

Figure 5 and Figure 6 illustrate the percentage difference in HSCW gain calculated from the survey data and estimated from the FSA Model and the difference between mean number of cattle on hand input into the survey and that estimated from the FSA Model for the 2002 and 2004 calendar years. A positive difference results from the model underestimating values and a negative difference results from the model overestimating values when compared with survey data.

Figure 5 and Figure 6 illustrate that feedlots were able to provide very good estimates of total cattle numbers in and out and total liveweight in and out. Hence, errors between HSCW gain calculated from survey data and that estimated from the FSA Model are typically less than 1%, with the exception of Feedlot 3 and Feedlot 6 in 2002. Consequently, results standardised per kg HSCW gain have small inherent errors, with the exception of Feedlots 3 and 6 in 2002.

Errors were found between the mean number of cattle on-hand from the survey data and that estimated from the FSA Model across all feedlots. Errors ranged from –9% to 24% and –20 to 55% for the 2002 and 2004 survey years respectively. Hence, results calculated from, or based on the mean number of cattle on hand potentially have large inherent errors.

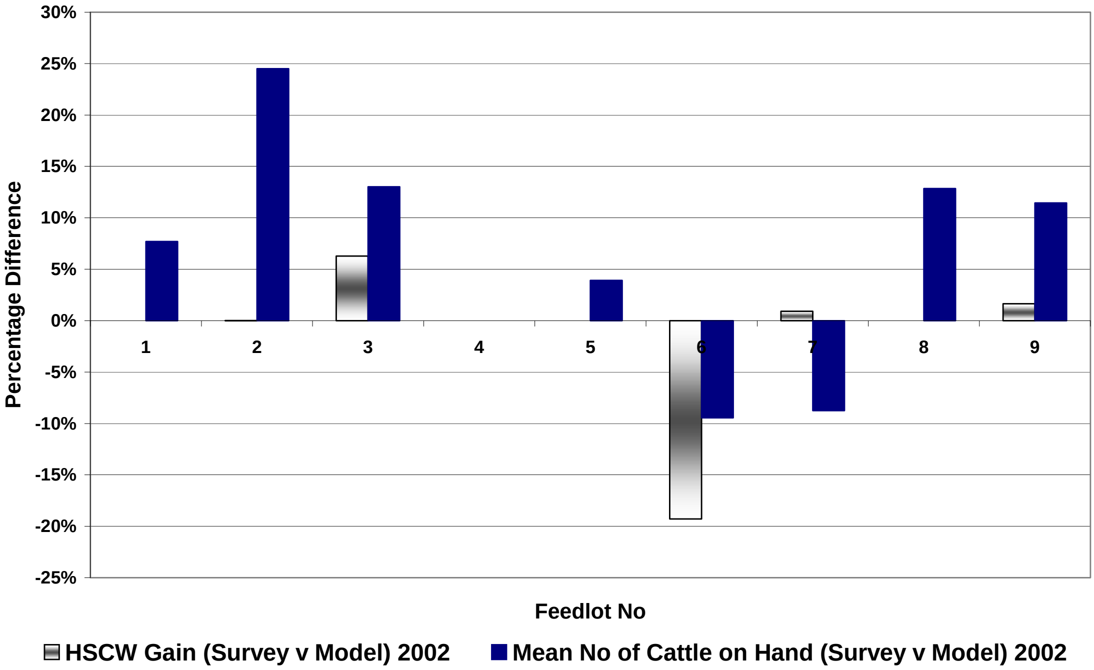


Figure 5 – Percentage Difference between Survey Data and Model Estimation for 2002 survey year.

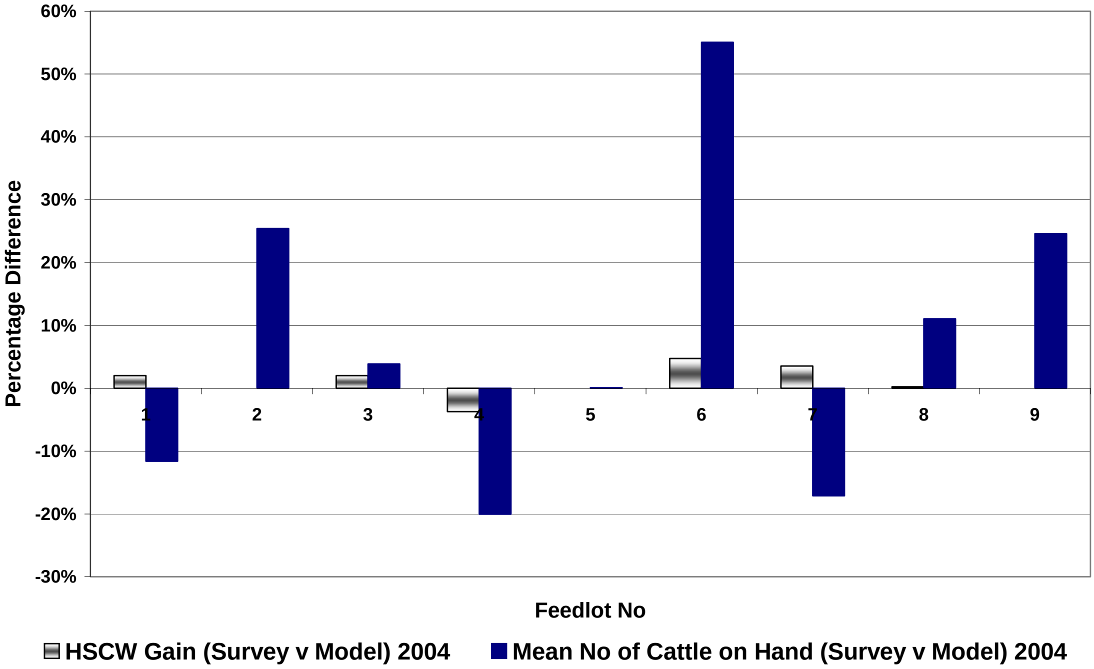


Figure 6 – Percentage Difference between Survey Data and Model Estimation for 2004 survey year.

7 Results and Discussion

7.1 Energy Consumption

7.1.1 Livestock Transport

The energy (fuel consumed) for transport of incoming and outgoing livestock was calculated from cattle numbers, intake and exit liveweight, truck transport type (fuel usage & loading capacity) and estimated mean distance travelled to and from the feedlot. Data on cattle numbers, intake and exit liveweights, truck transport type and estimates of mean distance travelled was collected directly from the survey. Truck fuel usage and loading capacity was calculated from best available data. The raw consumption data for the respective fuel type was then converted into an equivalent energy consumption and then standardised per kg HSCW gain.

Truck transport fuel usage was determined from gathering transport industry data on average fuel use per 100 km for different truck types. Table 3 shows the average fuel use per 100 km for different truck types commonly used for livestock transport. Fuel consumption is a function of the efficiency of vehicle weight, fuel technology, topography, road conditions as well as other factors. The fuel usage presented here is only an average based typical highway performance for fully loaded vehicles.

Table 3 – Fuel usage per 100km for livestock transport truck types.

	Table Top	Semi Trailer	Semi Trailer	B Double	Road Train
	1 Deck	1 Deck	2 Deck	3 Decks	4 Decks
Fuel (L) / 100 km	23.8	34.55	42.6	56.8	68.4

Loading capacity depends upon truck type and size of the livestock. Loading rates were taken from Davies, Blackwood and Richards (2002), NSW Agnote DAI-236 - Cattle transport costs - calculator instructions for different truck types commonly used for livestock transport. Table 4 shows average livestock loading rates for different truck types commonly used for livestock transport.

From Table 4, and the number of incoming and outgoing cattle, it was possible to calculate the number of incoming and outgoing vehicles. When multiplied by the estimated travel distance, the total kilometres of livestock transport was calculated. From Table 3, it was possible to estimate fuel use.

Table 4 – Livestock loading rates (head per vehicle) for livestock transport truck types.

Animal LWT	Table Top	Semi Trailer	Semi Trailer	B double	Road Train
kg	1 deck	1 deck	2 decks	3 decks	4 decks
250	22	38	75	114	150
300	20	34	67	102	134
350	18	30	60	91	120
400	16	28	55	83	110
450	15	25	51	77	102
500	14	24	47	71	94
550	13	22	43	65	86
600	12	20	39	59	78
650	11	18	35	54	70
700	10	16	32	49	64
750	9	14	28	44	56
800	8	12	24	39	48

Figure 7 illustrates the energy consumed (MJ) per kilogram of HSCW gain for nine surveyed feedlots for incoming and outgoing cattle. These feedlots represent a cross section of small (1000) to large (25,000) scale operations and are located geographically from Victoria to Queensland. Figure 7 clearly shows the impact of travel distance on energy consumption for incoming cattle. Cattle sourced close to feedlots (Feedlots 1, 2, 5, 6, 7, 8 & 9) have lower (0.5-1.25 MJ/kg HSCW gain) energy consumption when compared with Feedlots 3 & 4 which source cattle from greater distances (2.5-3.0 MJ/kg HSCW gain). Similarly, all feedlots with the exception of Feedlot 9 are located in close proximity to abattoirs, thus energy consumption for cattle leaving the feedlot is typically less than 1.0 MJ/kg HSCW gain.

7.1.2 Commodity Delivery

The energy (fuel consumed) for transport of commodities to the feedlot was calculated from the annual mass of each commodity delivered, type of truck delivering commodity (fuel usage & loading capacity) and estimated mean delivery distance. Data on annual volumes of commodity delivered, truck type and mean delivery distance was collected directly from the survey. Truck fuel usage and loading capacity was calculated from best available data.

Table 5 shows the average fuel use per 100 km for different truck types commonly used for commodity transport. Fuel consumption varies depending upon the efficiency of vehicle weight, fuel technology, topography, road conditions and other factors. The fuel usage presented here is only an average based typical highway performance for fully loaded vehicles.

Table 5 – Fuel usage per 100km for commodity transport truck types.

	Body Truck, 10t	Truck and Dog	Semi Trailer	B Double	Road Train
Fuel (L) / 100 km	23.8	42.6	42.6	56.8	68.4

Loading capacity depends upon truck type and the density of the commodity delivered. The loading capacity was determined from gathering transport industry data on average commodity loading rates for different truck types. Table 6 shows average loading capacity for different truck types commonly used for commodity transport.

Table 6 – Commodity loading rates for transport truck types.

Commodity	Body Truck, 10t	Truck and Dog	Semi Trailer	B Double	Road Train
	tonnes	tonnes	tonnes	tonnes	tonnes
Roughages/Straws	6	12	12	18	24
Fully prepared ration	12	24	24	36	48
Liquids	12	24	24	36	48
Major Grains	12	24	24	36	48
Molasses	12	24	24	36	48
Protein Sources	12	24.5	25.5	37	50
Silage	12	25	25	36	50

Figure 7 illustrates the energy consumed (MJ) per kilogram of HSCW gain for commodity delivery for nine surveyed feedlots. Only data from 2004 was available for Feedlot 4. Figure 7 clearly shows the impact of travel distance on energy consumption for commodity delivery. Commodities sourced close to the feedlot (Feedlot 1, 3, 4, 5, 6, 7 & 8) have lower (0.5 MJ/kg HSCW gain) energy consumption compared with Feedlots 2 and 9 which source commodities from greater distances, resulting in energy consumptions of 1.5 and 3.5 MJ/kg HSCW gain respectively.

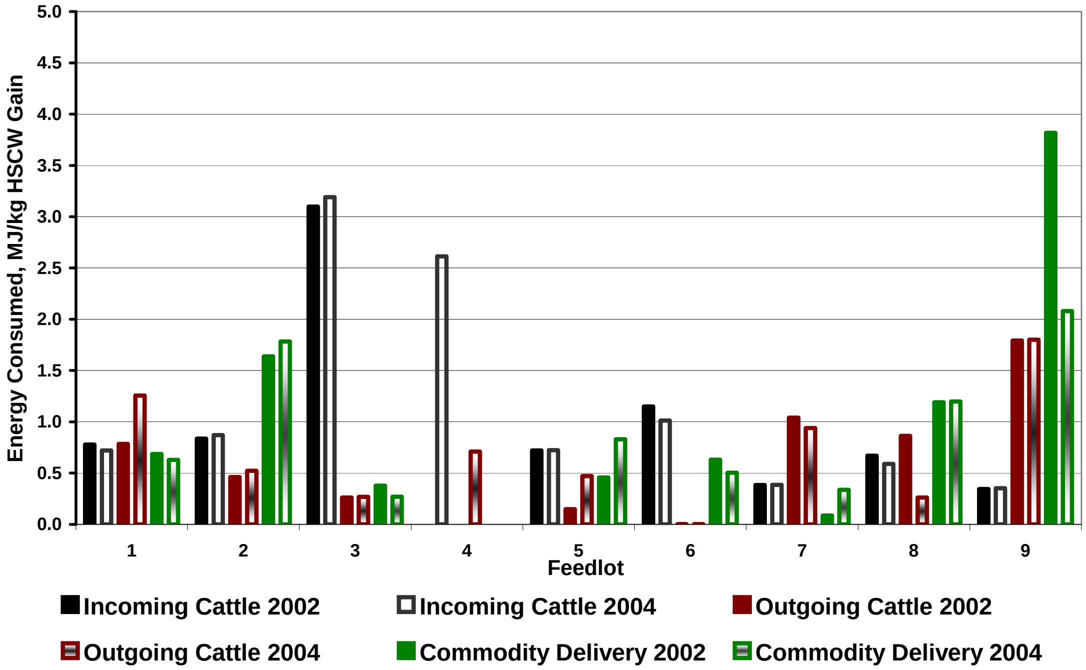


Figure 7 – Energy consumed per kilogram of HSCW gain for livestock transport and commodity delivery.

7.1.3 Feed storage and processing

The annual usage for feed preparation and processing of fuel type diesel, petrol, LPG, butane, electricity or solid fuel (coal/wood) was required to be input into the survey. The energy consumed for the respective fuel types was then calculated using the conversion factors listed in Table 7. The energy consumed was then standardised per kg HSCW gain. Only one feedlot was unable to supply information pertaining to energy consumption for feed processing.

Table 7 – Energy conversion factors for various fuel types.

Fuel Type	Fuel Density kg/L	Units of Measure	Energy Conversion Factor (Unit to MJ)
Diesel	0.836	Litres	38.6
Petrol	0.739	Litres	34.2
LPG	0.51	Litres	25.7
Butane	0.568	Litres	28.1
Butane	0.568	Litres	28.1
Electricity	1	kWhr	3.6
Coal	1	Tonne	19700

The average amount of energy used for feed processing is a function of the processing system. Figure 8 illustrates the energy consumption for feed processing for nine surveyed feedlots. Feedlots 3 & 8 temper their grain, whilst Feedlot 4 reconstitutes its grain. This results in low energy consumption in the order of 0.25 MJ/kg HSCW gain when compared with steam flaking (Feedlots 1, 2, 7 & 9) which can consume over nine times the energy (4.4 MJ/kg HSCW gain). The fuel source has a large impact on the energy consumption. Consider Feedlot 1, in year 2002 it had a higher energy consumption (4.4 MJ/kg HSCW gain) than in 2004 (2.3 MJ/kg HSCW Gain) resulting from a change in fuel source.

The percentage energy usage from individual feedlot sectors within three feedlots with varying feed processing systems (viz steam flaking, reconstitution and steam flaking) are shown in Figures 10, 11 and 12. When steam flaking is used to process grain, the energy needed for feed processing is 45% to 70% of the total energy use in the feedlot. This is similar to the results found by Sweeten (1990). Grain reconstitution uses significantly less energy (32%) as a percentage of overall feedlot energy use. Feed processing is the single largest consumer of energy in the feedlot sub-system.

7.1.4 Feed Delivery/Feedlot Area

Where individual records allowed, the annual usage of individual fuel types (diesel, petrol, LPG or butane) for vehicles within the feedlot area (feed delivery trucks, pen cleaning equipment, bobcats, water trucks, quads etc.) was required to be input into the survey. The raw consumption data was then converted into an equivalent energy consumption using the conversion factors listed in Table 7. Energy consumed in feed delivery and the feedyard is the second largest use of energy in the feedlot sub-system. Energy consumption ranges from 0.4 in Feedlot 5 to 2.5 MJ/kg HSCW gain in Feedlot 1. This is a six-fold range. However, the influence of pen cleaning frequency and method may partly explain this. The pen layout, location in relation to the feedmill and feed truck age and type may partly explain the higher energy consumption of Feedlots 1 and 9 during feed delivery. Paine et al. (n.d) suggest that careful feedlot layout design can result in 25% less travel.

7.1.5 Water Supply

Where individual feedlot records allowed, the annual usage of fuel type (diesel, petrol, LPG, butane, electricity) by equipment used to supply and distribute clean water from its original source for cattle drinking/washing etc was required to be input into the survey. The raw consumption data was converted into an equivalent energy consumption using the conversion factors listed in Table 7. Electricity was the main fuel type used in the supply of water. Only one feedlot operator was unable to supply information pertaining to water supply energy use.

Energy used to supply water to the feedlot is typically less then 0.15 MJ/kg HSCW gain, with the exception of Feedlot 3, which had more than double the average energy consumption, 0.35 MJ/kg HSCW gain. This probably resulted from the design of the water supply and delivery system at this particular feedlot.

The percentage energy usage from individual feedlot sectors within three feedlots with varying feed processing systems (viz steam flaking, reconstitution and steam flaking) are shown in Figures 10, 11 and 12. The data in these figures show that the amount of energy needed for water supply was about 1% of the total energy use of the feedlots. This is lower than the 2.5% result found by Sweeten (1990) for Texas feedlots. However, data from the US Industry may be inflated because of the need to maintain trough overflows in winter to prevent freezing.

7.1.6 Administration

The annual fuel usage by administration equipment was required to be input into the survey. As electricity was the main fuel type used to operate administration facilities (office equipment and staff amenities etc), data was only gathered from feedlots with a separate electricity meters for their office. Three feedlot respondents were unable to supply separate data. The raw data was then converted into an equivalent energy consumption using the conversion factors listed in Table 7. The energy consumed was then standardised per kg HSCW gain.

Energy used to operate administration facilities is typically less then 0.1 MJ/kg HSCW gain, with the exception of Feedlot 9 which has more than double the average energy consumption, 0.2 MJ/kg HSCW gain.

From Figures 8, 9 and 10, the energy needed to operate the office is in the order of 1%. This is lower than the 5% result found by Lipper et al. (1976).

7.1.7 Effluent Irrigation

The annual usage of diesel, petrol, LPG, butane or electricity for effluent irrigation equipment was required to be input into the survey. Photograph 11 illustrates a holding pond and associated irrigation pumping equipment. The raw consumption data for the respective fuel types was then converted into an equivalent energy consumption using the conversion factors listed in Table 7. The energy consumed was then standardised per kg HSCW gain.

Diesel, petrol and electricity were the fuel types most commonly used to operate irrigation pumping equipment. Half of the survey respondents were unable to supply separate energy consumption or had zero consumption for the survey years.

Energy consumed in the operation of irrigation pumping is typically less then 0.1 MJ/kg HSCW gain, with the exception of Feedlots 1 and 2 which consume, 0.2 and 0.3 MJ/kg HSCW gain respectively.

Three feedlots with varying feed processing systems (viz steam flaking, reconstitution and steam flaking) are shown in Figures 8, 9 and 10. They illustrate that energy required for irrigation pumping as a percentage of total energy use is in the order of 1%.

Photograph 11 – Holding pond and associated irrigation pumping equipment

7.1.8 Farming Activities

The annual usage of diesel, petrol, LPG, butane or electricity to operate farming equipment for planting, slashing, spraying, harvesting etc. was required to be input into the survey. The raw consumption data for the respective fuel type was then converted into an equivalent energy consumption using the conversion factors listed in Table 7. The energy consumed was then standardised per kg HSCW gain.

Diesel was the fuel most commonly used as the energy source for other farming activities. Energy consumed in the operation of other farming activities ranged from less than 0.1 MJ/kg HSCW gain to 0.77 MJ/kg HSCW gain. This variation is due to the size of farming area associated with the feedlot system and the climatic conditions for the survey years. Some feedlots have large tracts of land and are able to grow crops for the feedlot. Diesel consumed in activities used to grow crops for the feedlots falls outside the boundary of the sub-system for the feedlot sector. However, it was difficult to partition these activities from activities used within the sub-system such as general slashing, vehicle use etc.

Three feedlots with varying feed processing systems (viz steam flaking, reconstitution and steam flaking) are shown in Figures 8, 9 and 10. They illustrate that energy required for other farming activities as a percentage of total energy use is in the order of 6% and is a significant component of the total energy use.

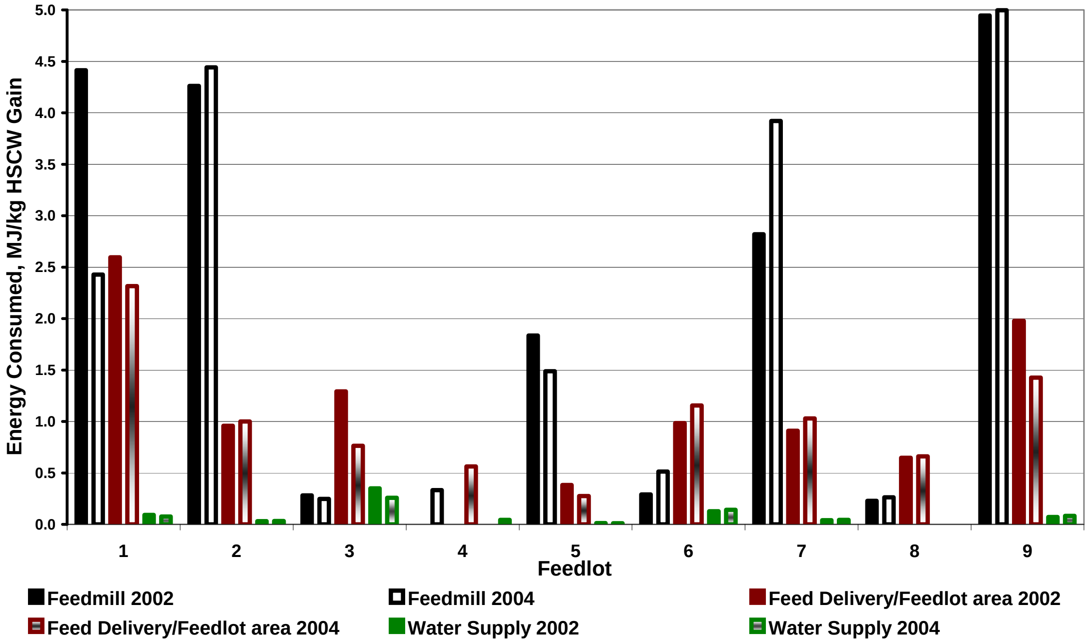


Figure 8 – Energy consumed for feed processing, feed delivery/feedlot area and water supply for 2002 and 2004 survey years.

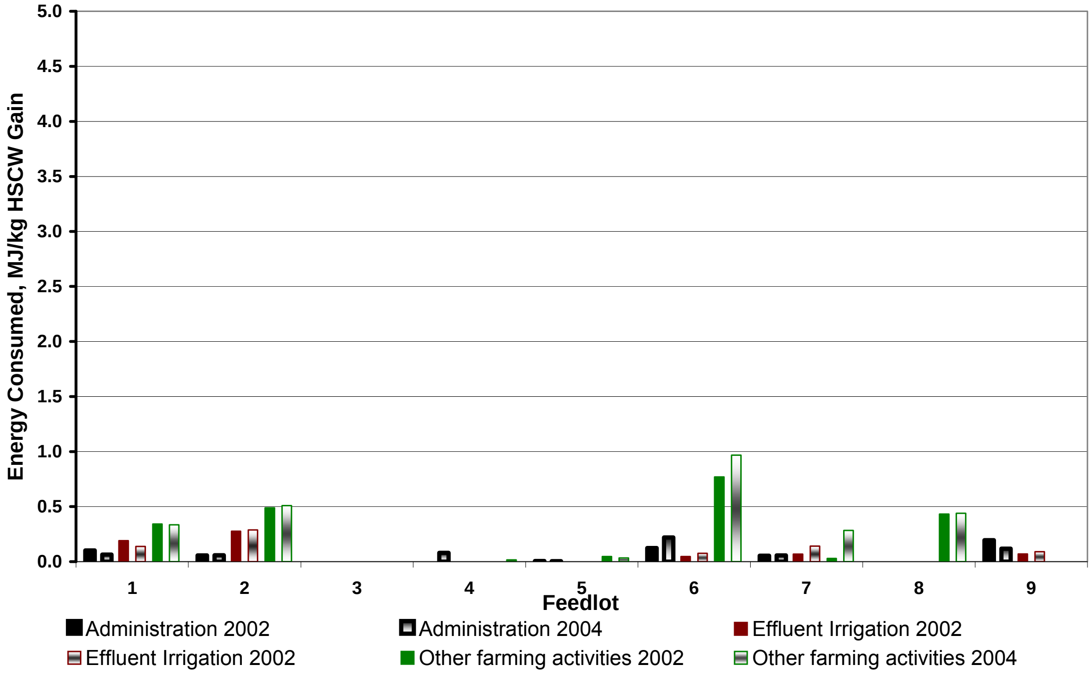


Figure 9 – Energy consumed for administration, irrigation and other farming activities for 2002 and 2004 survey years.

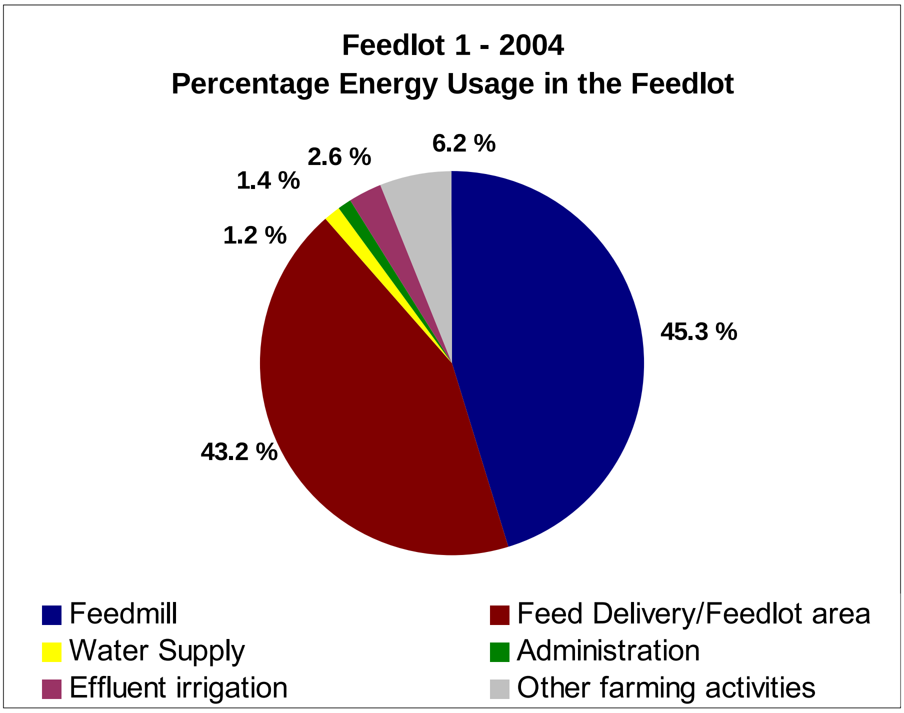


Figure 10 – Percentage of energy consumed from operations in the feedlot during 2004 – Feedlot 1.

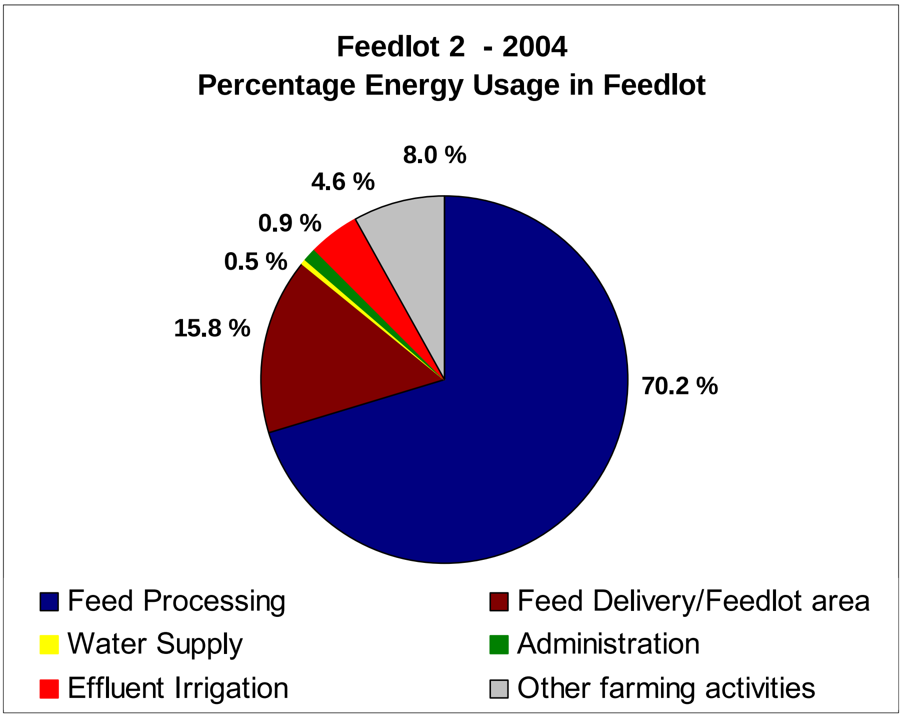


Figure 11 – Percentage of energy consumed from operations in the feedlot during 2004 – Feedlot 2.

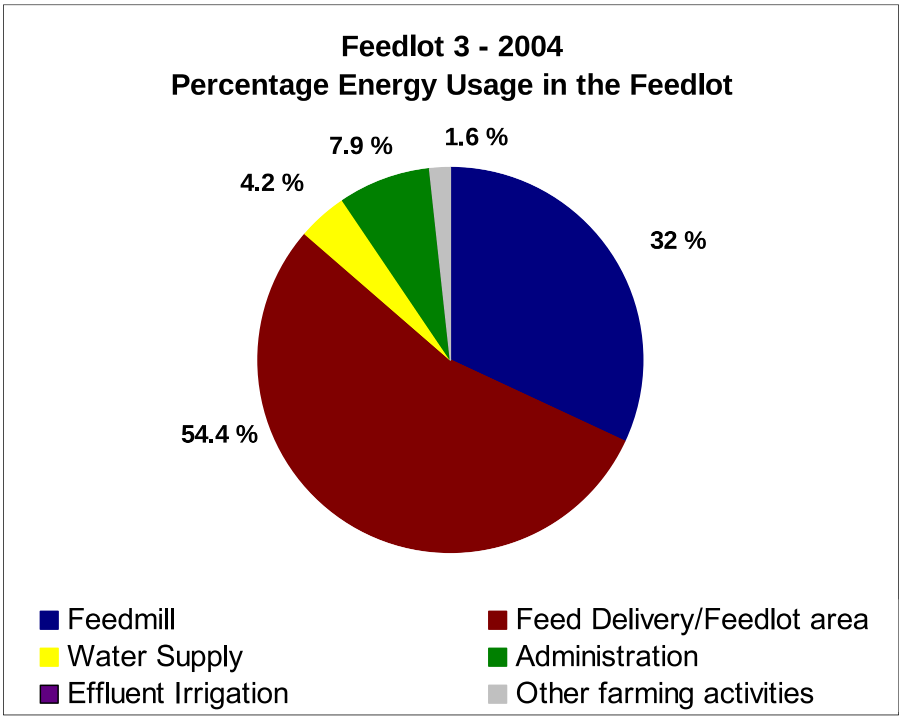


Figure 12 – Percentage of energy consumed from operations in the feedlot during 2004 – Feedlot 7.

7.1.9 Total Energy Consumption

Total energy consumption was calculated by totalling livestock transport, commodity delivery, feed processing, feed delivery/feedlot area, water supply, administration and effluent irrigation sectors and then standardised per kg HSCW gain. Table 8 and Table 9 present a worst case and best case scenario for energy consumption for the 2002 and 2004 survey years respectively. That is, the total of the maximum and minimum energy consumption for each sector from individual feedlots is presented. For incoming/outgoing cattle and commodity delivery the worst case scenario represents larger distances travelled whilst best case represents small distances. For feed processing worst case represents steam flaking and best case represents tempering/reconstitution. Similarly, for water supply worst case represents high pumping whilst best case represents gravity feed supply. In 2002, total energy consumption was found to range from 17.8 to 1.14 MJ/kg HSCW gain. In 2004, a smaller range was found with a maximum total energy of 12.8 and minimum of 1.4 MJ/kg HSCW gain.

Table 8 – Maximum and minimum energy consumption across individual sectors for 9 surveyed feedlots in 2002.

Feedlot Sector	Maximum Energy Consumption MJ/kg HSCW gain (Worst Case)	Minimum Energy Consumption MJ/kg HSCW gain (Best Case)
Incoming Cattle	3.10	0.34
Outgoing Cattle	1.79	0.00
Commodity Delivery	3.82	0.08
Feed processing	4.94	0.23
Feed Delivery/Feedlot Area	2.59	0.38
Water Supply	0.35	0.01
Administration	0.20	0.01
Effluent Irrigation	0.28	0.05
Farming Activities	0.77	0.03
Total	17.8	1.14

Table 9 – Maximum and minimum energy consumption across individual sectors for 9 surveyed feedlots in 2004.

Component	Maximum Energy Consumption MJ/kg HSCW gain (Worst Case)	Minimum Energy Consumption MJ/kg HSCW gain (Best Case)
Incoming Cattle	1.01	0.35
Outgoing Cattle	1.80	0.00
Commodity Delivery	2.08	0.34
Feed processing	5.00	0.26
Feed Delivery/Feedlot Area	1.43	0.27
Water Supply	0.14	0.01
Administration	0.22	0.06
Effluent Irrigation	0.14	0.08
Farming Activities	0.97	0.02
Total	12.79	1.40

Figure 15 illustrates the percentage maximum energy consumption across individual sectors for feedlots for the 2004.

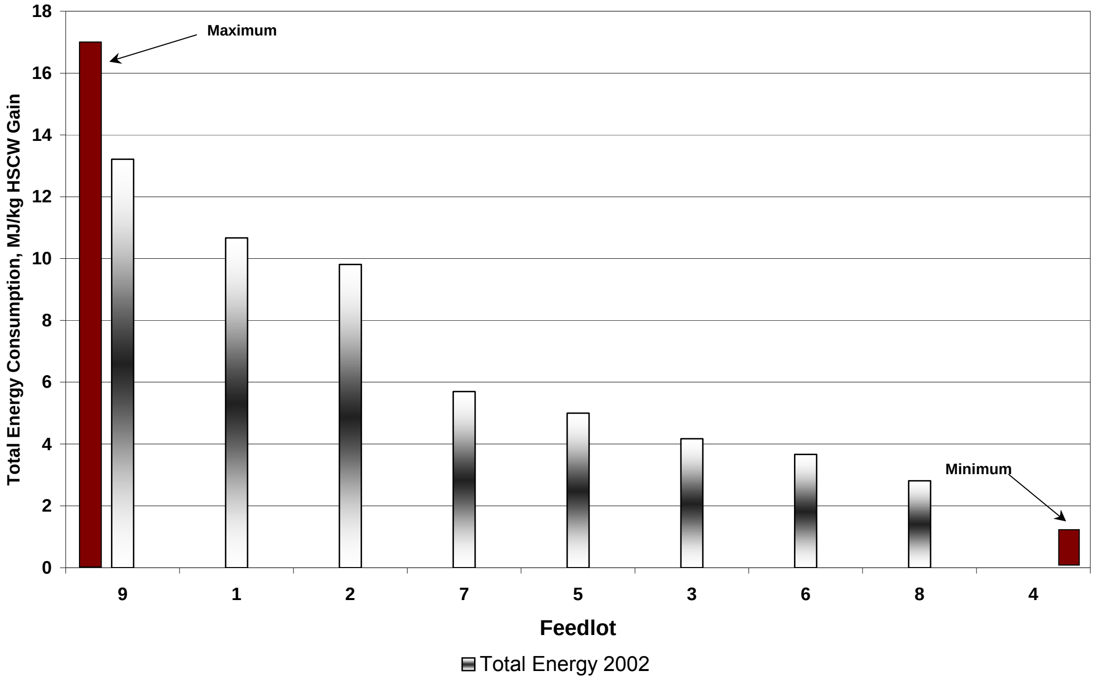


Figure 13 – Total energy consumption for individual feedlots for 2002 survey year.

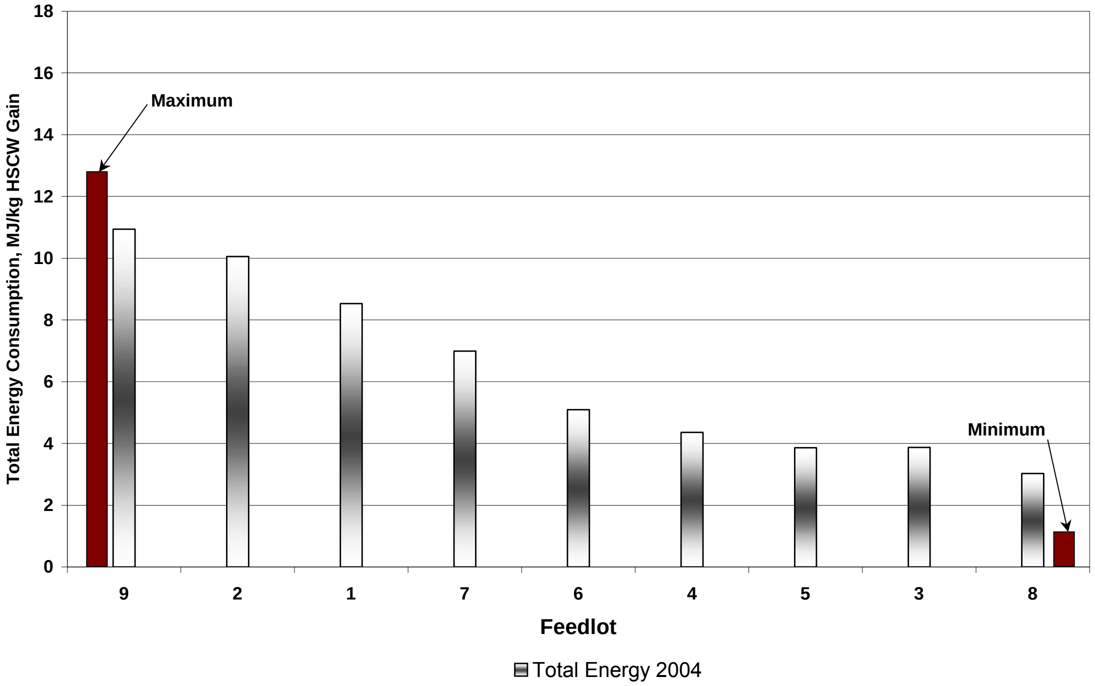


Figure 14 – Total energy consumption for individual feedlots for 2004 survey year.

Figure 13 and Figure 14 illustrate the total energy consumption for individual feedlots for the 2002 and 2004 survey years respectively. The total maximum and minimum energy consumption across all feedlots (taken from Table 8 and Table 9) is also presented.

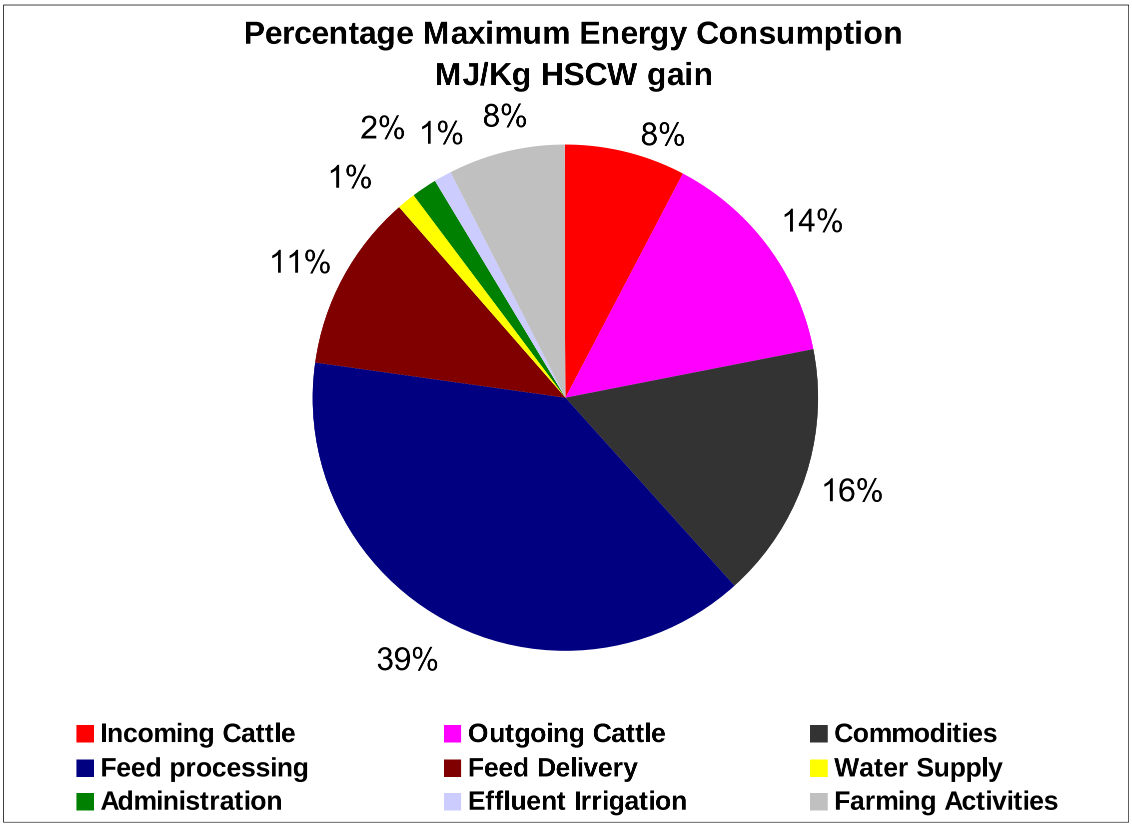


Figure 15 – Percentage maximum energy consumed from operations in the feedlot during 2004 for all feedlots.

7.2 Greenhouse Gas Emission

Data collected from the survey for cattle numbers, ration ingredients, incoming and outgoing livestock transport, delivery of feed commodities and feed processing, feed delivery, water supply, administration, irrigation was input into the FSA Model to allow the estimation of GHG emissions.

Estimations of the GHG emissions resulting from the livestock themselves, the livestock waste and those resulting from energy use, calculated using AGO standard Tier II methods, are presented.

Emissions of enteric methane, methane and nitrous oxide from waste were estimated and then expressed in kilograms of CO_2-equivalent (CO_2-e). Emissions from energy use were estimated and expressed as kilograms of CO_2-equivalent (CO_2-e). GHG emissions from all sources were then standardised per kg HSCW gain.

Figures 15, 16 and 17 present a percentage breakdown of GHG emissions from Feedlots 3, 4 and 6. Feedlot numbering is not consistent with energy use. This is to assist in protecting the identity of individual feedlot data (i.e. Feedlot 3 in the energy section does not correspond with Feedlot 3 in this section). Enteric methane emission represents the greatest percentage of GHG emissions in the order of 62% with nitrous oxide from manure accounting for 26% of GHG emissions. Manure methane accounts for 2% of total GHG emissions. Combined emissions from the energy used during livestock and commodity transport, feed processing, feed delivery and water supply account for 10% of the GHG emissions. Of these sectors feed processing can have the highest emissions, depending on the feed processing method.

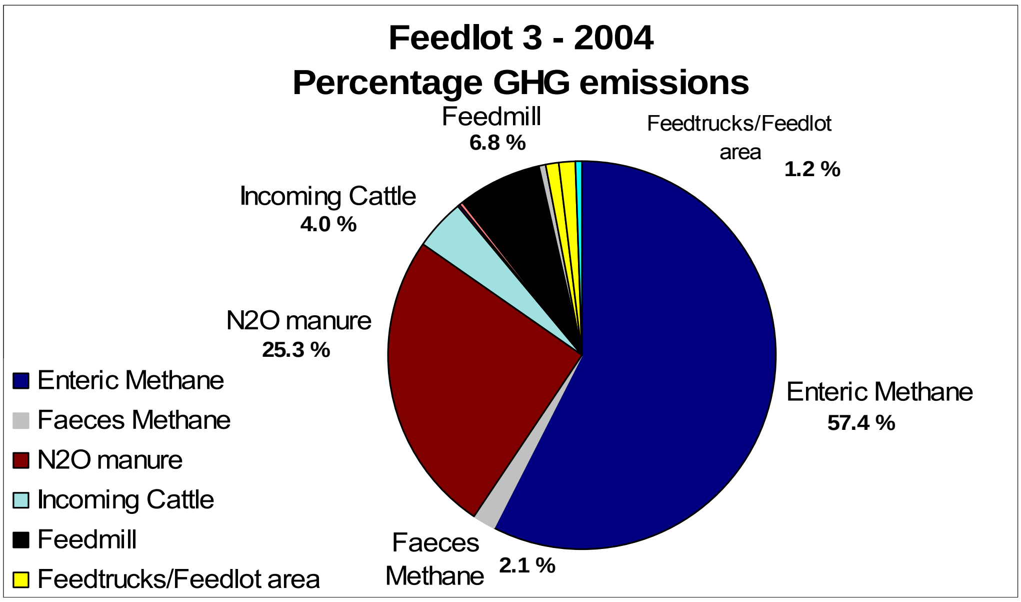


Figure 16 – Percentage of GHG emissions from operations in the feedlot during 2004 - Feedlot 3.

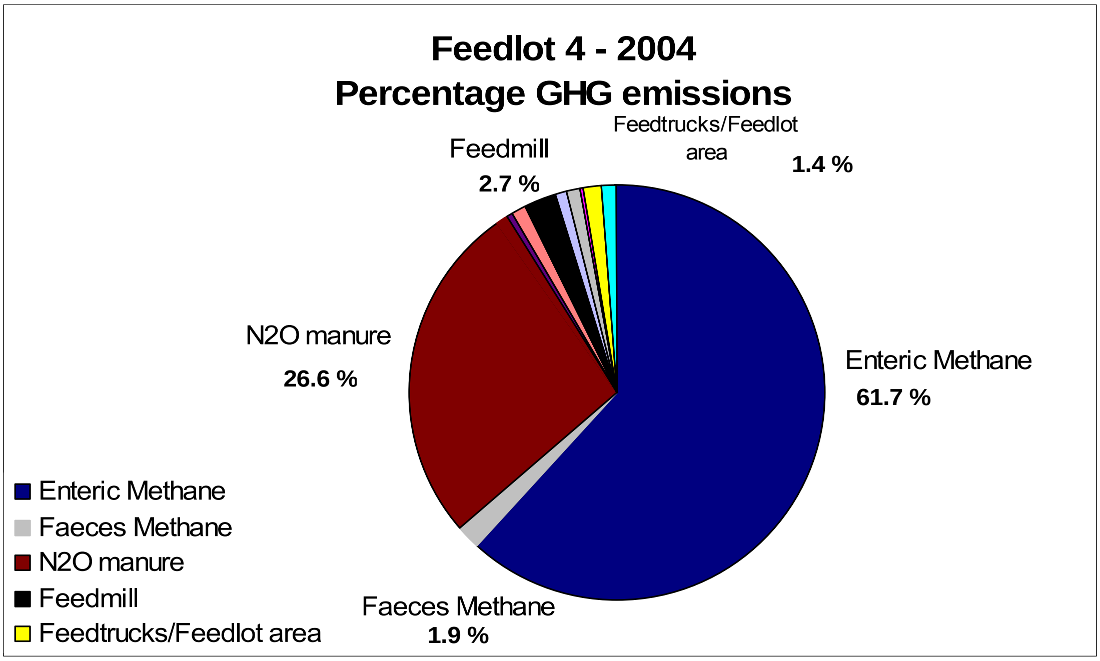


Figure 17 – Percentage of GHG emissions from operations in the feedlot during 2004 - Feedlot 4.

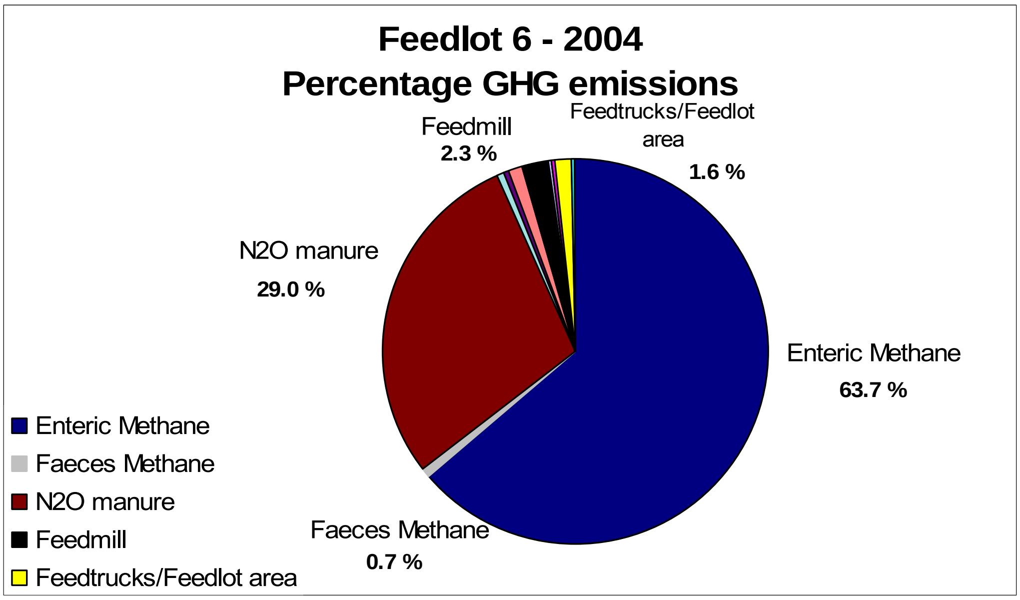


Figure 18 – Percentage of GHG emissions from operations in the feedlot during 2004 - Feedlot 6.

7.2.1 Emissions from Livestock

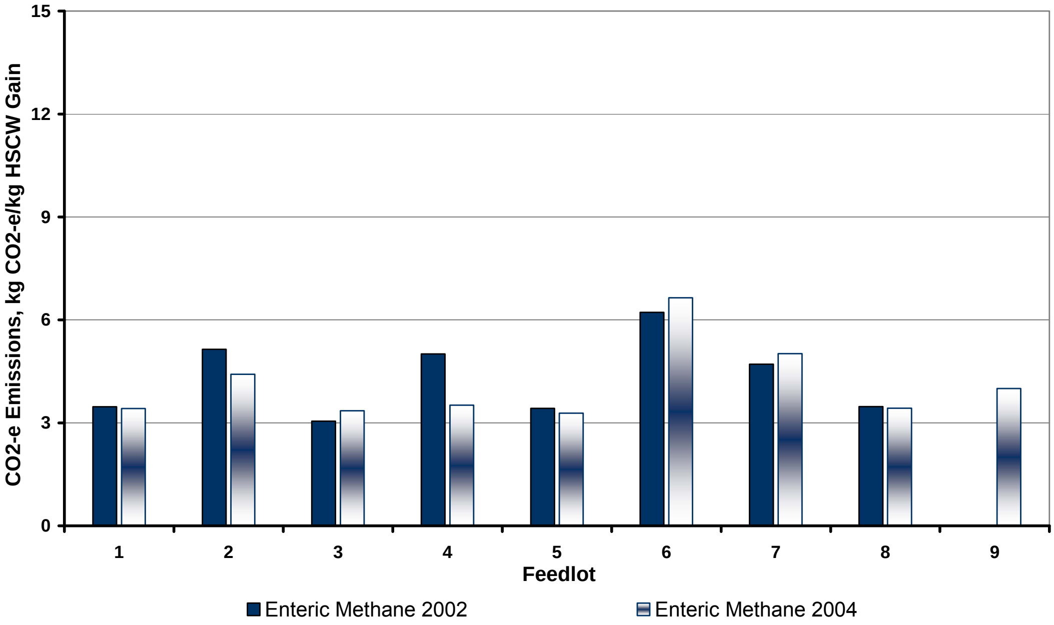


Figure 19 – Kilograms of CO_2-e per kg HSCW Gain for Enteric methane emissions for 2002 and 2004 survey data.

Enteric methane was found to range between 3.0-6.5 kg CO_2-e/kg HSCW gain (Figure 19). This is equivalent to methane emissions ranging from 0.078 kg CH_4/kg liveweight gain/day and 0.17 kg CH_4/kg liveweight gain/day. The enteric methane emissions depend upon the class of cattle in the feedlot with longer fed cattle (> 150 days) having higher enteric methane emission rates, greater than 5 kg CO_2-e/kg HSCW gain (Feedlots 2, 6, 7). This can be further demonstrated with Feedlot 4 which fed cattle for longer periods in 2002 than in 2004. Phetteplace et al. (2001) estimations of enteric methane emissions from feedlot cattle were 0.062 kg CH_4/kg liveweight gain. Harper et al. (1999) measured methane emissions from cattle on high-grain feedlot rations of 0.066 kg CH_4/kg liveweight gain. Similarly, McGinn et al. (2008) measured methane emissions of 0.166 kg CH_4/kg liveweight gain. However, McGinn et al. (2008) emissions are total methane emissions and include both enteric and faecal methane. The relative contribution of each is unknown.

7.2.2 Emissions Waste Handling, Storage and Utilisation

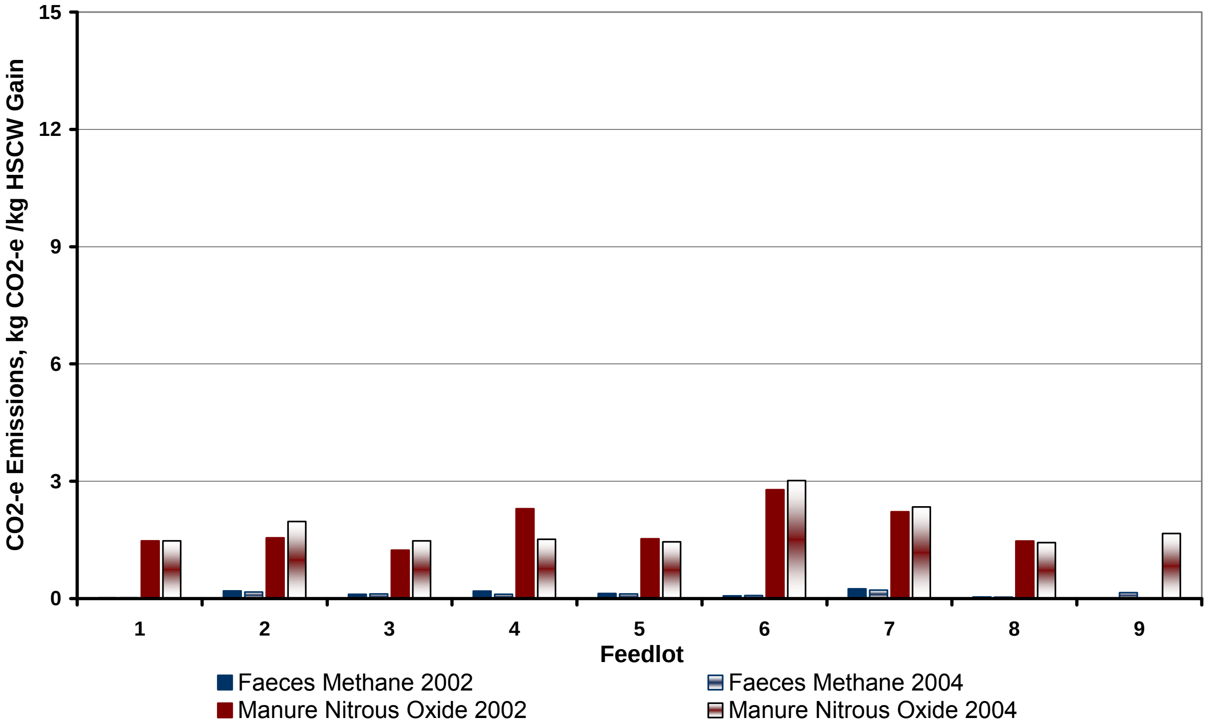


Figure 20 – Kilograms of CO_2-e for manure methane and nitrous oxide emissions for 2002 and 2004 survey data.

The emission of nitrous oxide from manure represents the second largest source of GHG emission accounting for 26% of total emissions. Nitrous oxide represents between 1.2-3.0 kg CO_2-e per kg HSCW gain with manure methane around 0.20 kg CO_2-e per kg HSCW gain. This is equivalent to Nitrous Oxide emissions ranging from 0.007 kg N_2O/kg liveweight gain to 0.017 kg N_2O/kg liveweight gain. Phetteplace et al. (2001) estimated nitrous oxide emissions of 0.007 kg N_2O/kg liveweight gain for US feedlot production systems.

Manure methane accounts for around 2% of total GHG emissions. The estimated manure methane emissions are equivalent to 0.005 kg CH_4/liveweight gain. Phetteplace et al. (2001) estimated manure methane emissions of 0.0095 kg CH_4/liveweight gain for US feedlot production systems. The default MCF value of 5% was used to calculate manure methane emissions for ‘warm’ regions (Queensland) and 1.5% for ‘temperate’ regions (NSW, Victoria). Thus, no consideration is given for anaerobic (wet pen) conditions in feedlot pens following rainfall. If a MCF is closer to that estimated by Steed and Hashimoto (1995) of around 66% for a wet anaerobic pen surface, then the current AGO method under-estimates emissions from manure methane. The AGO methodology assumes, that all manure within a feedlot is dry packed. Therefore, there is no consideration of nitrous oxide emissions from other manure management systems including stockpiling, composting or from holding ponds is given.

7.2.3 Emissions from Livestock and Commodity Transport

Emissions from the energy consumed during livestock and commodity transport represent a small proportion of the total GHG emissions. In total, they represent around 1 kg CO_2-e per kg HSCW gain with emissions directly proportional to delivery distances.

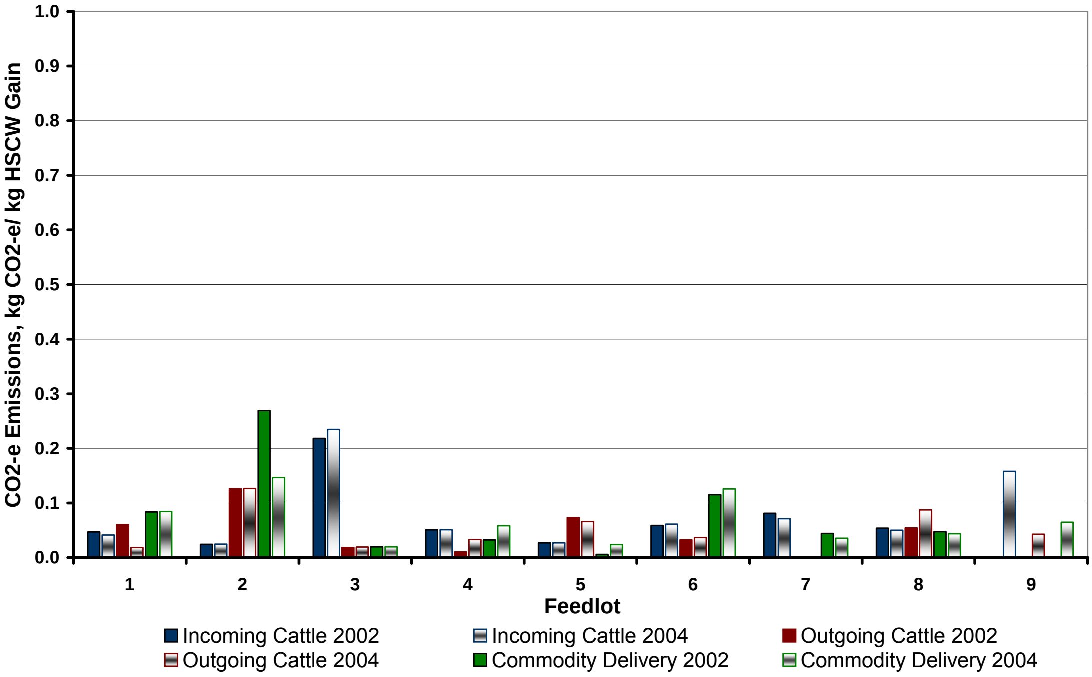


Figure 21 – Kilograms of CO_2-e per kilogram of HSCW gain from energy use for 2002 and 2004 survey data.

7.2.4 Emissions From Other Feedlot Activities

Emissions from the energy consumed during feed processing, feed delivery and water supply are presented in Figure 22. Figure 18 illustrates the emissions from the energy used in administration, irrigation pumping and other farming activities. Emissions from these sectors represent a small proportion of the total GHG emissions. In total they represent less than 1 kg CO_2-e per kg HSCW gain. Of these activities, feed processing has the highest emissions of around 0.1-0.5 kg CO_2-e per kg HSCW gain, depending upon type of feed processing system used.

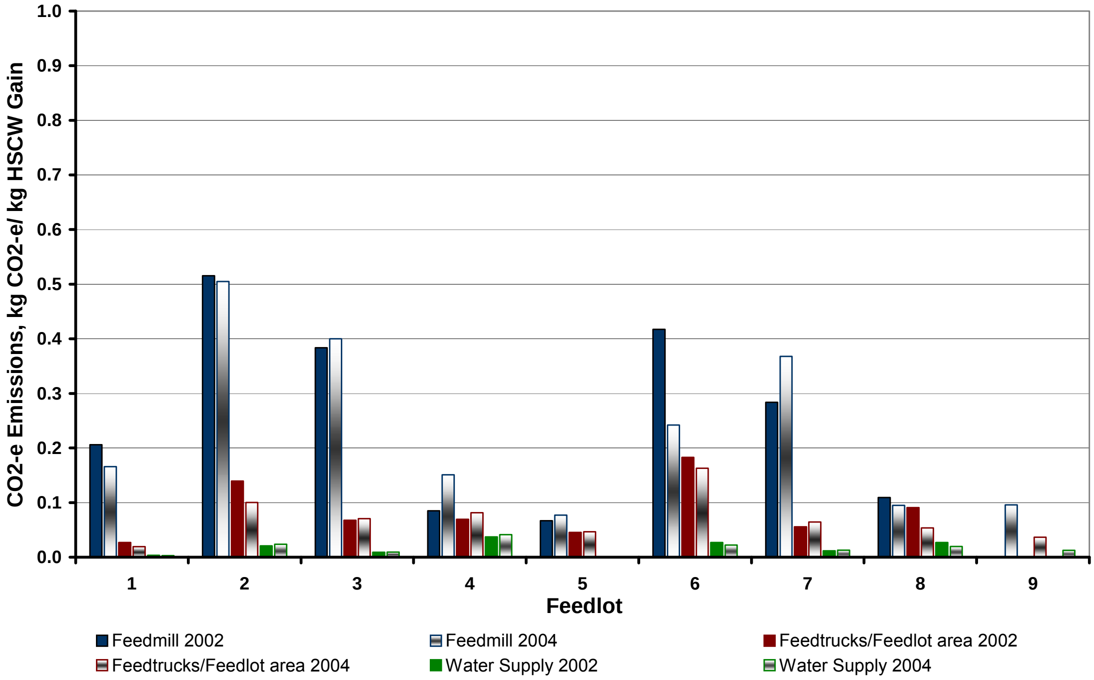


Figure 22 – Kilograms of CO_2-e per kilogram of HSCW gain from energy use for 2002 and 2004 survey data.

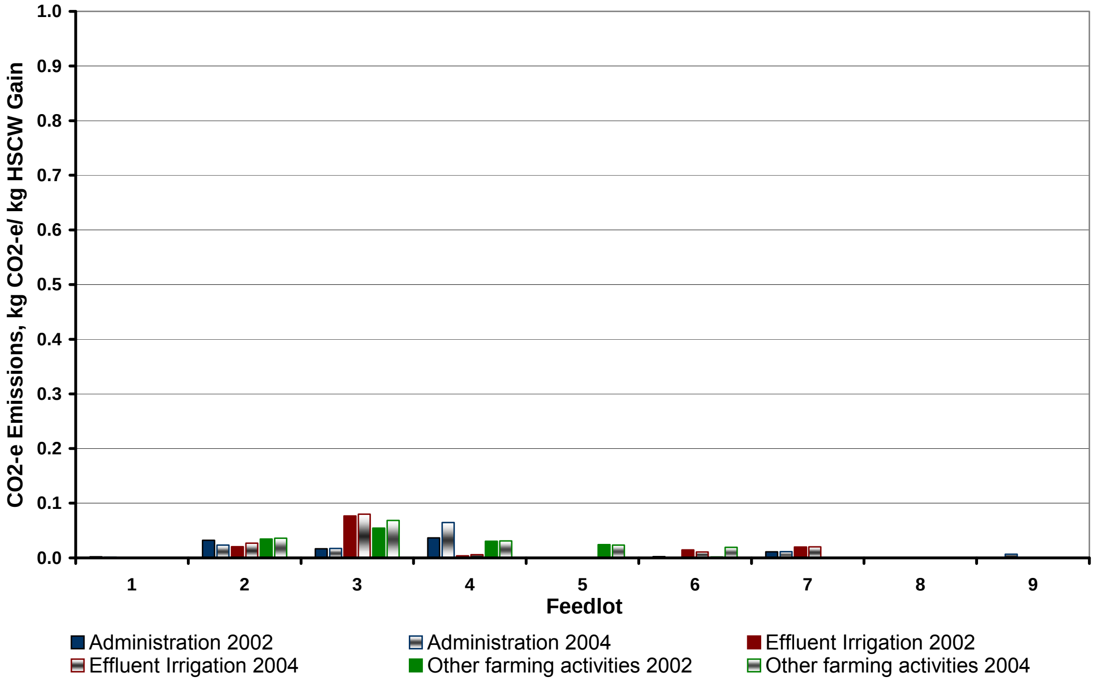


Figure 23 – Kilograms of CO_2-e per kilogram of HSCW gain from energy use for 2002 and 2004 survey data.

7.2.5 Total GHG emissions

Total GHG emissions were calculated by totalling livestock transport, commodity delivery, feed processing, feed delivery/feedlot area, water supply, administration and effluent irrigation sectors and then standardised per kg HSCW gain. Table 10 and Table 11 present a worst case and best case scenario for GHG emissions for the 2002 and 2004 survey years respectively. That is, the total of the maximum and minimum GHG emissions for each sector from individual feedlots is presented. For enteric methane, it is a reflection of the market types on feed. For incoming/outgoing cattle and commodity delivery the worst case scenario represents larger distances travelled whilst best case represents small distances. For feed processing worst case represents steam flaking and best case represents tempering/reconstitution due primarily to energy consumption. Similarly, for water supply worst case represents high pumping whilst best case represents gravity feed supply. In 2002, total GHG emissions were found to range from 4.5 to 10.8 kg CO_2-e / kg HSCW gain. In 2004, a similar range was found with a maximum total GHG emissions of 11.3 and minimum of 4.9 kg CO_2-e / kg HSCW gain.

Table 10 – Maximum and minimum GHG emissions across individual sectors for 9 surveyed feedlots in 2002.

Feedlot Sector	Maximum GHG Emission kg CO_2-e / kg HSCW gain/ year (Worst Case)	Minimum GHG Emission kg CO_2-e / kg HSCW gain/ year (Best Case)
Enteric Methane	6.22	3.05
Faeces Methane	0.25	0.04
Manure Nitrous Oxide	2.78	1.20
Incoming Cattle	0.22	0.03
Outgoing Cattle	0.13	0.00
Commodity Delivery	0.27	0.01
Feedmill	0.52	0.07
Water Supply	0.04	0.01
Administration	0.04	0.01
Effluent Irrigation	0.08	0.01
Feedtrucks/Feedlot area	0.18	0.05
Other farming activities	0.05	0.02
Total	10.8	4.50

Table 11 – Maximum and minimum GHG emissions across individual sectors for 9 surveyed feedlots in 2004.

Feedlot Sector	Maximum GHG Emission kg CO_2-e / kg HSCW gain/ year (Worst Case)	Minimum GHG Emission kg CO_2-e / kg HSCW gain/ year (Best Case)
Enteric Methane	6.64	3.28
Faeces Methane	0.22	0.04
Manure Nitrous Oxide	3.02	1.43
Incoming Cattle	0.23	0.02
Outgoing Cattle	0.13	0.00
Commodity Delivery	0.15	0.02
Feedmill	0.51	0.08
Water Supply	0.04	0.01
Administration	0.06	0.01
Effluent Irrigation	0.08	0.01
Feedtrucks/Feedlot area	0.16	0.04
Other farming activities	0.07	0.02
Total	11.3	4.96

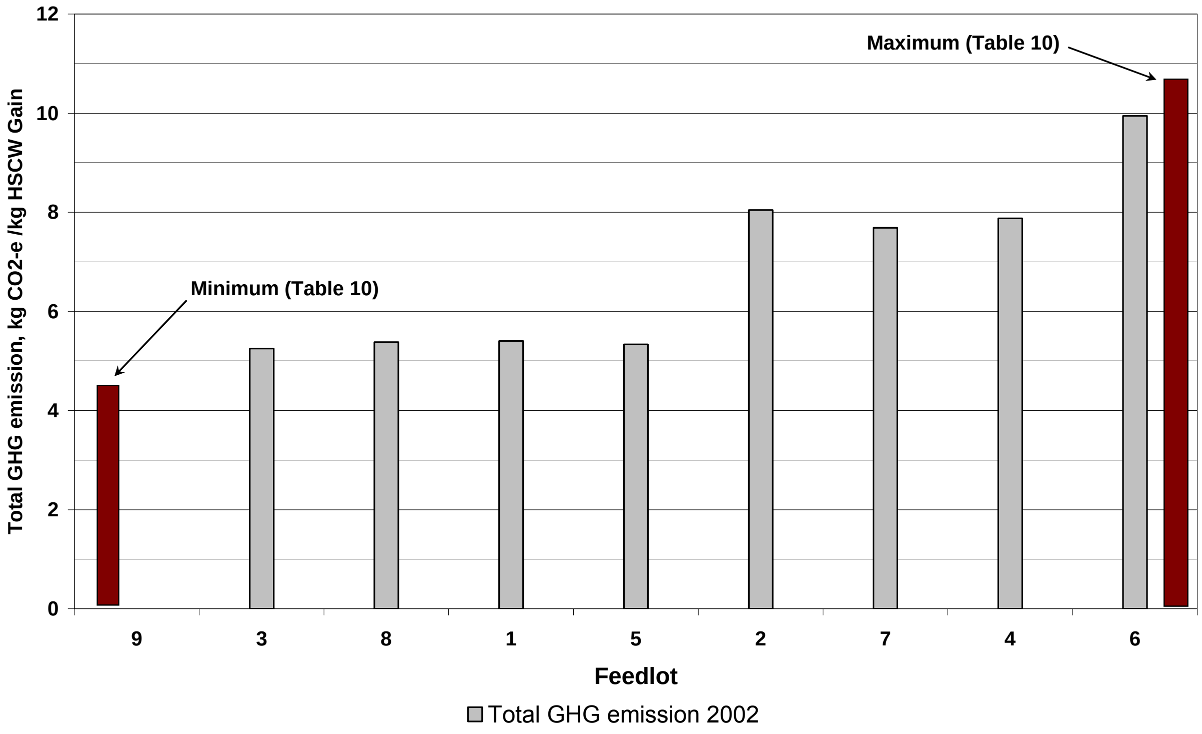


Figure 24 – Total GHG emissions for individual feedlots for 2002 survey year.

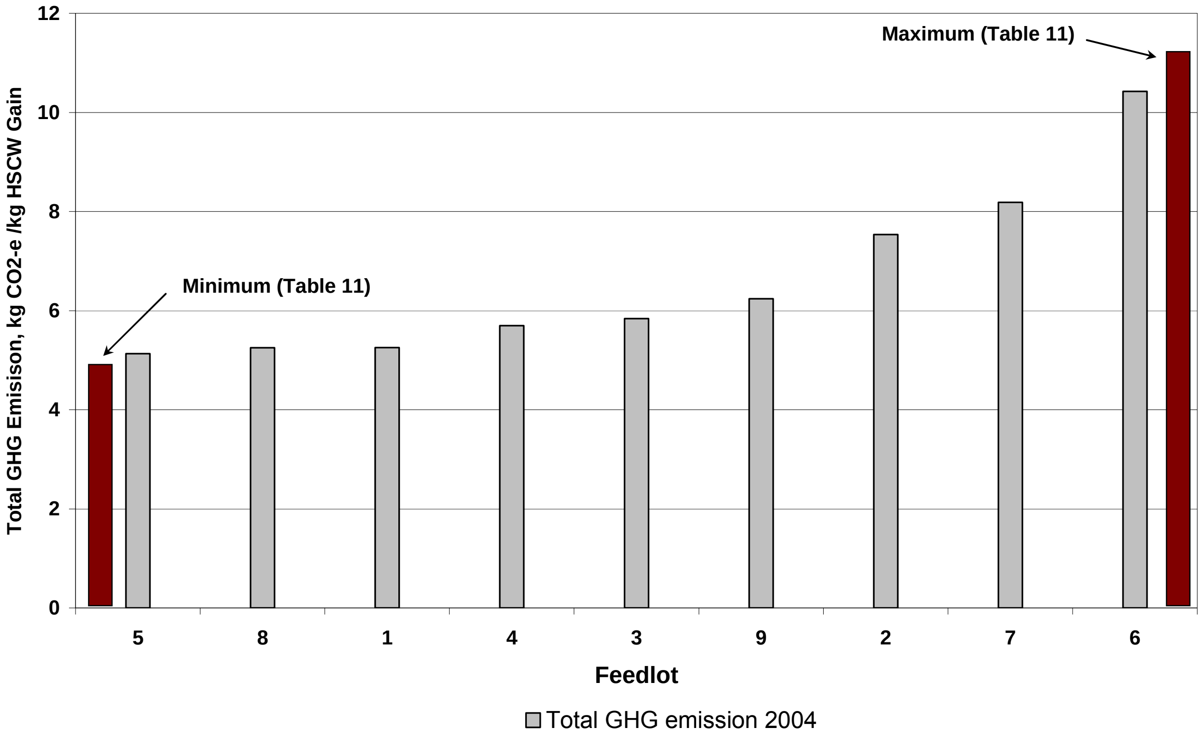


Figure 25 – Total GHG emissions for individual feedlots for 2004 survey year.

Figure 24 and Figure 25 illustrate the total GHG emissions for individual feedlots for the 2002 and 2004 survey years respectively. The total maximum and minimum GHG emissions across all feedlots (taken from Table 10 and Table 11) is also presented.

8 Conclusions and Recommendations

8.1 Conclusions

Little work has been undertaken to evaluate energy consumption by feedlots. Energy use by feedlots was collected through several studies in North America in the 1970's and 1980's. This study is the first to examine energy consumption by Australian feedlots.

Distance travelled by trucks transporting cattle and delivering feed has a large impact on the energy consumed. Combined these represent the largest source of energy consumption (indirect) within the feedlot subsystem. Short transport distance for incoming cattle uses some 0.5-1.25 MJ/kg HSCW gain while longer transport distances use some 2.5-3.0 MJ/kg HSCW gain. Sourcing commodities close to the feedlot uses 0.5 MJ/kg HSCW gain while sourcing feedstuffs from further afield uses 1.5-3.5 MJ/kg HSCW gain. Hence, sourcing cattle and commodities close to feedlots and locating feedlots close to abattoirs minimises energy consumed in these processes.

The average energy used for feed processing depends mainly on the processing system used. Energy consumption ranges from 0.25 MJ/kg HSCW gain (tempering) to 4.4 MJ/kg HSCW gain (steam flaking). Feedlots using steam flaking have over nine times the energy consumption of those that reconstitute or temper their grain. Feed processing is the single largest consumer of energy in the feedlot sub-system, accounting for up to 70% of the total energy consumption.

Energy used in feed delivery and the feedyard is the second largest consumer of direct energy in the feedlot sub-system, accounting for 15-40% of total energy use depending upon the feed processing system used, pen cleaning frequency, pen layout, location in relation to the feedmill and feed truck age and type are contributing factors for feed delivery/feedyard energy consumption.

In 2002, total energy consumption was found to range from 1.14 to 17.8 MJ/kg HSCW gain. In 2004, energy consumption ranged from a minimum of 1.4 to a maximum of 12.8 MJ/kg HSCW gain.

The outcomes of this study will allow the feedlot industry to develop a better understanding of the impact and relativity that various feedlot sector operations have on overall energy consumption. This information is invaluable for future design and management considerations. This study offers individual feedlot operators the opportunity to identify options for conserving energy in the feedlot and estimated cost benefits for alternative management practices if they were implemented.

Knowledge of the total energy consumption will allow the industry to benchmark itself against other intensive or extensive livestock industries and or industrial processes.

GHG emissions were estimated using standard GHG office methodology for feedlots. This methodology does not appear to accurately reflect the manure and effluent management systems used at Australian feedlots. Hence, estimates of GHG from manure management may be too low. However, we have no data to support this.

Enteric methane emissions represents the greatest single source of GHG emissions from the feedlot sub-system accounting for up to of 62% of total emissions. Enteric methane emission rates depend upon the class of cattle in the feedlot, with longer fed cattle (> 150 days) having a higher enteric methane production than shorter fed cattle (< 150 days).

Nitrous oxide emission from manure represents the second largest source of GHG emissions from the feedlot sub-system accounting for up to of 26% of total emissions.

Manure methane accounts for 2% of total GHG emissions. The default MCF value of 5% was used to calculate manure methane emissions for ‘warm’ regions (Queensland) and 1.5% for ‘temperate’ regions (NSW, Victoria). Thus, no consideration is given for anaerobic (wet pen) conditions in feedlot pens following rainfall. If the MCF for feedlot manure is closer to that estimated by Steed and Hashimoto (1995) of around 66% for a wet anaerobic pen surface, then the current AGO method under-estimates emissions from manure methane. Also, no consideration of nitrous oxide emissions from other manure management systems including stockpiling, composting or from holding ponds is given.

Combined emissions from the energy used during livestock and commodity transport, feed processing, feed delivery and water supply account for 10% of the GHG emissions. Of these sectors feed processing can have the highest emissions, depending on the feed processing method.

8.2 Recommendations

Whilst the type and detail of the information collected in this study allowed evaluation of total energy consumption and relativity between feedlot operations it did not consider the partitioning of energy consumption between feed delivery and manure management. The energy consumption of these two operations is important for assessment of alternative management practices. Hence further research in this area is recommended. This may include the type of manure management system used (mounding v more frequent removal) and the efficiency of feed delivery i.e. pen layout relative to feed processing systems, feed delivery management (1 larger capacity truck v 2 smaller capacity trucks etc). Gaining a better understanding of the efficiency of feed delivery may also be an important consideration in optimising feedlot layouts.

Nitrous oxide emission from manure represents the second greatest single source of GHG emissions from the feedlot sub-system accounting for up to of 26% of total emissions. Manure methane accounts for 2% of total GHG emissions. The AGO method gives no consideration of emissions from manure management systems other than dry pen conditions. Thus, no consideration is given for anaerobic (wet pen) conditions in feedlot pens following rainfall. Also, no consideration of nitrous oxide emissions from other manure management systems including stockpiling, composting or from holding ponds is given.

Hence, it is strongly recommended that research on GHG emissions from manure under differing management and climatic conditions be researched.

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10 Appendix A – Tables for Calculating Methane and Nitrous Oxide Emissions.

Table 12 – Symbols used in algorithms for feedlot cattle (NGGIC 2004).

State (i)	Feedlot Cattle Classes (duration of stay) (j)	Average Length of Stay (days)
i = 1 NSW/ACT	j = 1 Domestic/(70-80 days)	75
i = 2 Tasmania	j = 2 Export/(80-200 days)	140
i = 3 Western Australia	j = 3 Japan ox/(200+ days)	250
i = 4 South Australia		
i = 5 Victoria		
i = 6 Queensland		
i = 7 Northern Territory		

Table 13 – Mean liveweight (kg) of feedlot cattle by class for all States (NGGIC 2004).

Feedlot Cattle Class	Average time on Feed	Average time on Feed
	1990-1995a	1996-2001b
domestic/ 75 days 300 360	domestic/ 75 days 300 360	domestic/ 75 days 300 360
export/ 140 days 385 490	export/ 140 days 385 490	export/ 140 days 385 490
Jap ox/ 250 days 575 565	Jap ox/ 250 days 575 565	Jap ox/ 250 days 575 565

a. Working Group estimates
b. van Sliedregt et al. (2000)

Table 14 – Intake (kg/day) of feedlot cattle by class for all States (NGGIC 2004).

Feedlot Cattle Class/Average time on Feed	1990-1995a	1996-2001b
domestic/ 75 days	7.20	9.8
export/ 140 days	8.47	11.7
Jap ox/ 250 days	11.50	11.0

a. Working group estimates based on the assumption that intake is 2.4%, 2.2% and 2.0% of liveweight for domestic, export and Japanese ox markets respectively.
b. van Sliedregt et al. (2000)

Table 15 – Proportion of the four components of feed for feedlot cattle (NGGIC 2004).

	Total grain (incl. molasses)	Other Concentrates	Grasses	Legumes
1990-1995a	0.708	0.072	0.118	0.102
1996-2001b	0.779	0.048	0.138	0.035

a. Based on livestock working group estimates
b. van Sliedregt et al. (2000)

Table 16 – Composition of diet components (NGGIC 2004).

Diet Components.	Concentrates[a]		Roughage[a]	
	Grain	Other	Grass	Legume
Cellulose	0.07	0.19	0.31	0.36
Hemicellulose	0.04	0.11	0.31	0.20
Soluble residue	0.68	0.19	0.21	0.21
Nitrogen	0.02	0.05	0.026	0.032

a. Based on AFIC 1987 and livestock working group estimates

Table 17 – Nitrous oxide emission factors for the different manure management systems (NGGIC 2004).

Manure Management System	Emission Factor (kg N_20-N/kg excreted)
Anaerobic Lagoon	0.001
Liquid systems	0.001
Daily Spread	0
Solid Storage and drylot	0.02
Digesters	0.001

final report

Project code: **FLOT.328 C**

Prepared by: **RW Tucker, RJ Davis, K Klepper, PJ Watts and EJ McGahan**
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Environmental Sustainability Assessment of the Australian Feedlot Industry

Part C Report: Nutrient Cycling at Australian Feedlots

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Abstract

The Australian red meat industry, as with most primary industries, is coming under increasing pressure from both the community and government to document and justify its impacts on the environment. This project addresses the public misconceptions of the environmental sustainability of the feedlot industry by providing information on the quantities of nutrients supplied to the feedlot and the fate and quantity of nutrient leaving the feedlot.

Extensive research has been undertaken in the areas of animal growth and body composition, the factors that influence feed intake and digestibility, feed composition and waste management. Reported values for the quantities of nutrients excreted by lot-fed cattle are highly variable.

Factual site-specific information on cattle numbers, diet ingredients, market type, days on feed, manure production and effluent quality was collected from Australian cattle feedlots under a range of climatic, size and management conditions. Data from nine feedlots were collected over the 2002 and 2004 years.

This report provides factual information on the quantity of nutrients required to produce red meat within the feedlot sector only and the fate of these nutrients. These data for N, P and K are suitable for input into the life cycle inventory component of the feedlot sub-system.

Executive Summary

The Australian red meat industry, as with most primary industries, is coming under increasing pressure from both the community and government to document and justify its impacts on the environment. Currently, a lack of credible supply chain data prevents the industry from being able to respond in a meaningful manner.

Meat and Livestock Australia (MLA) is undertaking a project (COMP.094) that will address these issues and provide credible data on the industry's environmental impacts and sustainability for use by industry, including its interactions with government, community groups and the media. This project will utilise the standardised tool, Life Cycle Analysis (LCA), to quantify natural resource consumption and environmental interventions to water, soil and air.

LCA is a form of cradle-to-grave system analysis developed for use in manufacturing and processing industries to assess the environmental impacts of products, processes and activities by quantifying their environmental effects throughout the entire life cycle. An LCA is essentially a quantitative study. Sometimes environmental impacts cannot be quantified due to a lack of data or inadequate impact assessment models. Quantitative analysis requires standardised databases of main processes (e.g. energy, transport) and software for managing the study's complexity.

As part of the overall industry project, the beef cattle lotfeeding sector is undertaking a related project (FLOT.328) that will contribute to the whole of industry dataset, but more importantly addresses the public misconceptions of the environmental sustainability of the feedlot industry. It will identify and quantify the environmental costs associated with the production of one kilogram of grained beef to enable comparison with its domestic competing products (grass fed beef, lamb, pig and poultry meats).

Extensive research has been undertaken in the areas of animal growth and composition and the factors that influence feed intake and digestibility, feed composition and waste management. There is a wide variation in reported values for feedlot cattle nutrient excretion. Over the past ten years, there has been a significant development of the feedlot industry in terms of feeding for specific markets and in manure management. However, research into nitrogen losses through volatilisation of ammonia (NH_3) from feedlots systems has not kept pace with these changes.

This report covers the issue of the usage of one resource by feedlots – nutrients. It aims to provide factual information on the quantity of the major nutrients supplied to the feedlot and the fate and quantities of nutrients leaving the feedlot.

Factual site-specific information on cattle numbers, diet ingredients, market type, days on feed, quantity of manure produced and effluent concentrations was collected where possible from nine feedlots. The life cycle inventory for nitrogen (N), phosphorus (P) and potassium (K) within the feedlot sub-system was determined.

N enters the feedlot in incoming cattle (0.05-0.12 kg/kg HSCW gain) and feed (0.15-0.33 kg/kg HSCW gain). In this context, HSCW gain is the difference between total dressed carcass weight of cattle leaving the feedlot less the estimated total dressed carcass weight of cattle entering the

feedlot. The contribution of N from diet ingredients was found to range from 60-87% of the total N input. The level of N contained in individual diets varies between feedlots and within feedlots.

N is removed from the system in outgoing cattle (0.08-0.13 kg/kg HSCW gain) and manure (0.13-0.3 kg/kg HSCW gain). Hence, most N exits the feedlot in manure (50–80 %). Approximately 80% of the manure N is lost to the atmosphere from volatilisation, with the remainder exported in effluent and scraped manure.

The total P input level is around one-fifth of the total N input. It enters the system in incoming cattle (0.012-0.029 kg/kg HSCW gain) and feed (0.028-0.054 kg/kg HSCW gain). The contribution of P from feed is 47-80% of the total P input. P exits the system in outgoing cattle (0.023-0.038 kg/kg HSCW gain) and in manure (0.017-0.039 kg/kg HSCW gain). Variations in diet composition influence the level of P in manure, with cattle having higher P concentration in their diet correspondingly having a higher P concentration in their manure. P is present in scraped manure at 94-99% of the total P excreted in manure. The balance is contained in the effluent.

The total K into the system was 0.05-0.13 kg/kg HSCW gain. This is similar to the P inputs and around one-fifth of the total N inputs. Over 90% of the K into the system comes from feed. K out of the system is partitioned between outgoing cattle (0.01 kg/kg HSCW gain) and manure (0.06-0.09 kg/kg HSCW gain). The K output rates vary significantly between feedlots. This is mainly due to dietary variation, with cattle offered diets that have a high molasses content correspondingly having a high K content. The percentage of K retained in scraped manure ranges from 65-99%. The balance is exported in effluent.

The outcomes of this study will allow the feedlot industry to develop a better understanding of the relativity and pathways for nutrient cycling and provide factual information on the life cycle inventory for major nutrients.

Knowledge of the total nutrient input and output levels will allow the industry to benchmark itself against other intensive or extensive livestock industries and or industrial processes. More research into NH_3 losses from Australian feedlot pads, manure stockpiles and compost heaps, holding ponds, manure spreading and effluent irrigation is warranted. Further research into methods for minimising NH_3 losses from feedlot systems is also recommended.

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1 Background

The Australian red meat industry, as with most primary industries, is coming under increasing pressure from both the community and government to document and justify its impacts on the environment and its use of natural resources. This is evident through the government emphasis on industry initiatives such as the implementation of Environmental Management Systems (EMS) and Triple Bottom Line (TBL) reporting requirements. Currently, a lack of credible supply chain data prevents the industry from being able to respond in a meaningful manner.

Meat and Livestock Australia (MLA) is undertaking a project (COMP.094) that will address these issues and provide credible data on the industry's environmental impacts and sustainability for use by industry, including its interactions with government, community groups and the media. This undertaking will utilise the standardised tool, Life Cycle Analysis (LCA) to quantify natural resource consumption and environmental interventions to water, soil and air. A separate but related project (FLOT.328) is being undertaken for the lot feeding sector of the Australian red meat industry.

1.1 FLOT.328 Project Description

As part of the overall industry project, the beef cattle lot feeding sector is undertaking a related project that will contribute to the whole of industry dataset, but more importantly addresses the public misconceptions of the environmental sustainability of the feedlot industry by identifying and quantifying the environmental costs associated with the production of one kilogram of grained beef to enable comparison with its domestic competing products (grass fed beef, lamb, pig and poultry meats).

Given that environmental sustainability will eventually become a key element in maintaining and improving access for Australian product into key overseas markets, it is envisaged that the project will also benchmark these costs against international competitors (US and European beef) and identify areas of R&D investment to ensure the long-term viability and sustainability of the feedlot production system.

2 Project Objectives

The FLOT.328 project will:

1. Collect, collate and present relevant data to enable MLA to assess/benchmark the environmental sustainability of the feedlot industry against its domestic and international competitors by assessing the environmental costs associated with the production of one kilogram of meat from each production system,
2. Provide data for the feedlot industry suitable for use within the broader red meat supply chain Life Cycle Assessment (COMP.094),
3. Identify areas for potential future R&D investment to ensure long-term competitiveness, viability and sustainability of the feedlot production system, and
4. Communicate the results of the assessment to MLA in a format suitable for dissemination to industry stakeholders.

This report covers the issue of the usage of one resource by feedlots – nutrients. It aims to provide information on the quantities of nutrients supplied to the feedlot and the fate and quantities of nutrients leaving the feedlot.

2.1 Project Reporting Structure

This project includes the collection and analysis of a large quantity of data from operational feedlots on the environmental costs associated with the production of one kilogram of hot standard carcass weight (HSCW). In this context, HSCW gain is the difference between total dressed carcass weight of cattle leaving the feedlot less the estimated total dressed carcass weight of cattle entering the feedlot. To ensure all this data and information is presented in a suitable manner, six reports have been compiled.

A. Water Usage at Australian Feedlots. This report presents a background literature review of water usage at feedlots, data collection and results, as well as an analysis and discussion of the data collected. This report is the life cycle inventory for the water use component of the feedlot sub-system.

B. Energy Usage and Greenhouse Gas Emission Estimation at Australian Feedlots. This report presents a background literature review of energy usage and GHG emissions at feedlots, data collection and results. A discussion of results and the relative merits of the current GHG emission calculation methodology by the Australian Greenhouse Office (AGO) are included. This report is the life cycle inventory for the energy use and GHG emissions component of the feedlot sub-system.

C. Nutrient Cycling at Australian Feedlots. This report includes a literature review of nutrient pathways at feedlots, data collection and results as well as an analysis and discussion of the data collected. This report is the life cycle inventory for the nutrient cycling component of the feedlot sub-system.

D. NPI Listed Substances Emission Estimation for Australian Feedlots. This report provides a summary of the National Pollutant Inventory (NPI) reporting framework, data collection and results for category I listed substances. The report also includes a discussion of the relative merits of the current NPI emission estimation methodology, with guidance on an alternative method for use under Australian conditions.

E. Review of Lot Fed Cattle Water Consumption – MRC Project No. DAQ.079. This report provides a review of research undertaken in the early 1990's on water consumption in feedlots. It provides a more detailed literature review on the factors influencing drinking water requirements than is provided in Part A, experimental methodology, data collected and discussion of the results and outcomes of this MRC research.

F. Resource Use and Environmental Impact Assessment for Australian Feedlots. This report provides a summary of feedlot-relevant natural resources management (NRM) issues, data collection and results. A discussion of the environmental impact of the use of these resources by beef cattle feedlots is also included.

3 Life Cycle Assessment

Meat and Livestock Australia are undertaking a project (COMP.094) that will provide credible data on the red meat industry's environmental impacts and sustainability for use by industry, including its interactions with government, community groups and the media. This undertaking will utilise the standardised tool, LCA, to quantify natural resource consumption and environmental interventions to water, soil and air. This project (FLOT.328) is being undertaken for the lot feeding sector of the Australian red meat industry. The following description of LCA is taken from Peters et al. (2005).

3.1 Description of Life Cycle Assessment

LCA is a form of cradle-to-grave systems analysis developed for use in manufacturing and processing industries to assess the environmental impacts of products, processes and activities by quantifying their environmental effects throughout the entire life cycle. LCA can be used to compare alternative products, processes or services; compare alternative life cycles for a product or service; and identify those parts of the life cycle where the greatest improvements can be made. An international standard has now been developed to specify the general framework, principles and requirements for conducting and reporting LCA studies (Standards Australia 1998). LCA differs from other environmental tools (e.g. risk assessment, environmental performance evaluation, environmental auditing, and environmental impact assessment) in a number of significant ways. In LCA, the environmental impact of a product or the function a product is designed to perform is assessed, the data obtained are independent on any ideology and it is much more complex than other environmental tools. As a system analysis, it surpasses the purely local effects of a decision and indicates the overall effects.

There are four aspects of life cycle assessment (see Figure 1):

- *Goal and Scope Definition* defines the goal, functional unit and associated system to be studied.
- *Inventory Analysis* analyses all process inputs and outputs. It involves modelling unit processes in the system, considered as inputs from the environment (resources, energy) and outputs (product, emissions, waste) to the environment. Allocation of inputs and outputs needs to be clarified where processes have several functions (for example, one production plant produces several products). In this case, different process inputs and outputs are attributed to different goods and services produced. An extra simplification used by LCA is that processes are generally described without regard to their specific location and time of operation.
- *Impact Assessment* makes results from the inventory analysis more manageable and understandable in relation to natural environment, human health and resource availability.
- *Interpretation* involves evaluating inventory analysis and impact assessment outcomes against the study's goal.

An LCA is essentially a quantitative study. Sometimes environmental impacts cannot be quantified due to a lack of data or inadequate impact assessment models. A guide to decisions can then be qualitative use of LCA and use of other tools for supply chain analysis. Quantitative analysis requires standardised databases of main processes (energy, transport) and software for managing the study's complexity.

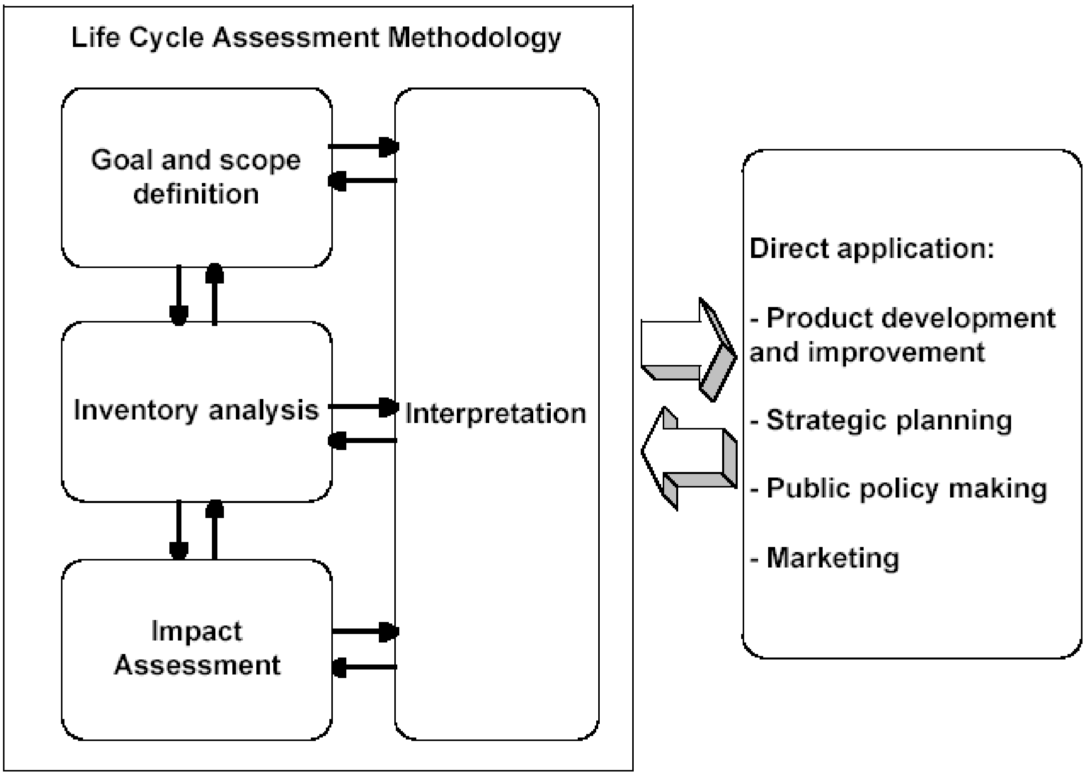

FIGURE 1 – GENERAL FRAMEWORK FOR LCA AND IT'S APPLICATION (STANDARDS AUSTRALIA 1998)

3.2 Selection of Functional Unit

The functional unit for this study is the delivery of one kilogram of hot standard carcass weight (HSCW) meat at the abattoir. AUS-MEAT is the authority for uniform specifications for meat and livestock in Australia. In March 1987, they introduced the term HSCW as a national standard. The HSCW is the fundamental unit of "over the hooks" selling and is the weight, within two hours of slaughter, of a carcass with standard trim (all fats out). This is a carcass after bleeding, skinning, removal of all internal organs, minimum trimming and removal of head, feet, tail and other items (AUS-MEAT, 2001). "Hot" indicates that the meat in question has not entered any chilling operations. This output-related functional unit was chosen, rather than an input-related one, in order to describe the human utility of the processes under consideration – the provision of nutrition for people. Although the meat could be served in different ways, this functional unit makes the different processes under consideration "functionally equivalent" from a dietary perspective.

3.3 System Boundaries

In LCA methodology, usually all inputs and outputs from the system are based on the 'cradle-to-grave' approach. This means that inputs into the system should be flows from the environment without any transformation from humans and outputs should be discarded to the environment without subsequent human transformation (Standards Australia 1998). Each system considers upstream processes with regard to the extraction of raw materials and the manufacturing of products being used in the system and it considers downstream processes as well as all final emissions to the environment.

Figure 2 shows the generalised system boundary for the red-meat sector as defined for the COMP.094 project. Within this boundary, there is a sub-system for the feedlot sector. The boundary chosen here (shown in red on Figure 2) is the feedlot site itself plus the transport component of bringing cattle and feed into the feedlot and delivering cattle from the feedlot. The production of feed for the feedlot will be examined in a larger system analysis.

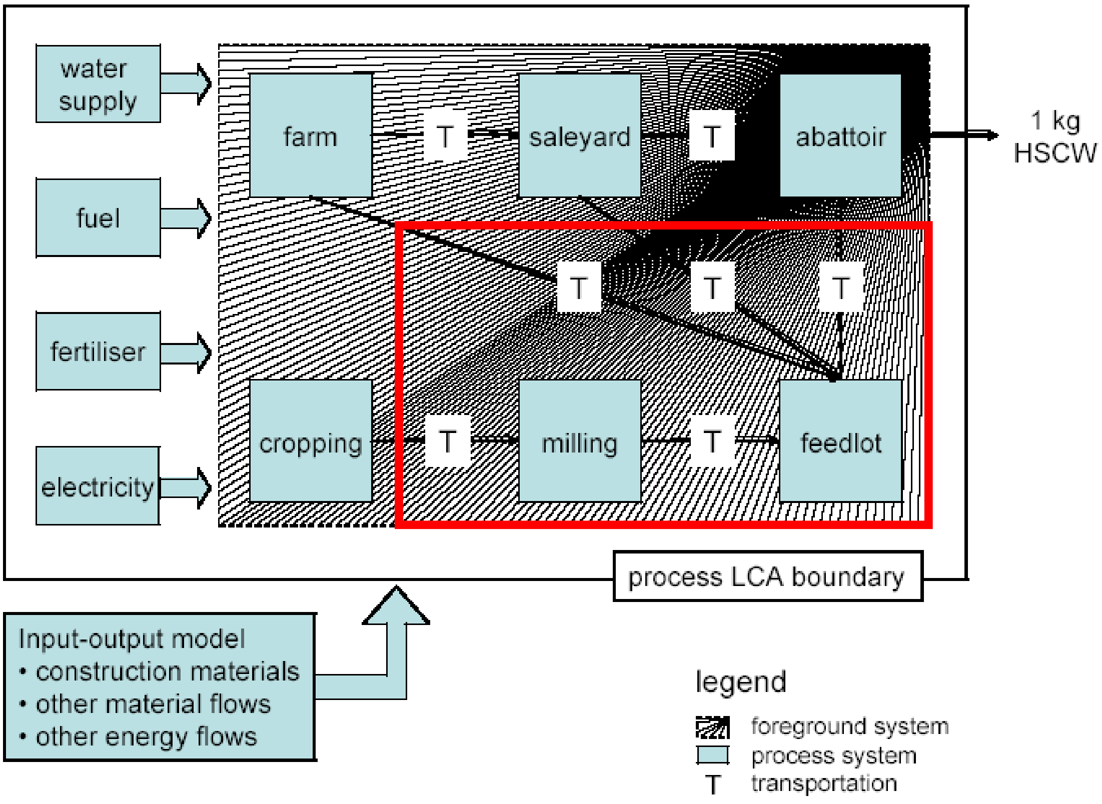

FIGURE 2 – GENERALISED SYSTEM MODEL FOR THE RED MEAT SECTOR WITH FEEDLOT SUB-SYSTEM

3.4 Life Cycle Inventory

Inventory analysis is the second phase in a life cycle assessment and is concerned with data collection and calculation procedures. The Inventory Analysis phase forms the body of the LCA as the majority of time and effort in an LCA is spent on Inventory Analysis. As a rule of thumb, 80 percent of the time required for an LCA is needed for this phase. The operational steps in preparing a life cycle inventory (LCI) are according to ISO 14041 (Standards Australia 1999):

- Data collection.
- Relating data to unit processes and/or functional unit.
- Data aggregation.
- Refining the system boundaries.

This report is the life cycle inventory for the nutrient cycling component of the feedlot sub-system.

4 Literature Review

4.1 Nutrient Pathways in Feedlots

Nutrient pathways in and out of cattle feedlot systems are complex and diverse. Nutrients enter the feedlot system via cattle, feed and water. Nutrients leave the feedlot via finished cattle, mortalities, scraped pen manure, effluent, products harvested from on-farm reuse areas, atmospheric losses and water flows. Inputs and feedlot management govern the concentration of nitrogen (N), phosphorus (P) and potassium (K) in each of these outputs. For instance, the weight of cattle on entry and exit, the diet of the cattle and the manure and effluent management treatment system all influence the nutrient balance. Furthermore, N volatilisation and leaching represent a significant nutrient output, with management the primary driver. Several key management areas have been identified within the feedlot boundary where processes affect nutrients, as shown in Figure 3.

The key management areas within the feedlot boundary include:

A. Cattle and feeding.
B. Pen surface.
C. Manure/compost stockpiling.
D. Holding pond.
E. Manure reuse areas.
F. Effluent reuse areas.

In the cattle and feed area, live cattle, water and diet components are nutrient inputs into the feedlot system. Generally, cattle entering feedlots are sourced from saleyards and properties. The age, sex and weight of these cattle vary depending on their source and target market. Whilst in the feedlot, cattle are fed specific diets for specific time periods to optimise cattle performance and meet target market requirements. Drinking water supplied to animals may be manipulated through the addition of essential vitamins or minerals to improve health and performance. Dietary composition varies within and between feedlots and commodity selection is largely price-driven. Outputs from this area are nutrients contained in cattle for slaughter and cattle mortalities during production. Quantities of nutrient imported and exported from the cattle and feed area are detailed in Section 4.2.

Cattle manure accumulates on the pen surface. The nutrient concentration of manure is mainly driven by the diet fed. However, manure is subject to decomposition on the pen surface and this affects its ultimate nutrient composition. External factors such as rainfall and pen cleaning also affect the nutrient concentration over time. Nutrient budgets and processes affecting nutrients on the pen surface are detailed in Section 4.3.

Manure is removed from feedlot pens periodically and the urine and rainfall runoff (effluent) are captured in a pond or ponds via designated drainage lines. Manure removed from the feedlot area is generally stockpiled or is composted in designated bunded areas with a flat compacted base. During stockpiling or composting, nutrients may be transformed and either concentrated or lost from the feedlot system. Processes that affect the quantity of nutrients contained in the manure during and after stockpiling or composting are described in detail in Section 4.4

A range of factors influence the concentration of nutrients contained in the effluent collected in sediment and holding ponds. These include the quantity of nutrients excreted by the cattle and climatic factors, particularly rainfall frequency and intensity and evaporation. Details on the quantity of nutrient entering and leaving the effluent stream are provided in Section 4.5.

Most manure reuse areas are used for crop or pasture production. These may be on-farm or off-farm (i.e. manure is sold or provided to others) or a combination of both. Manure from stockpiles or composted manure is applied to land using various techniques and incorporation methods. Weather conditions combined with management can significantly influence N volatilisation and N, P and K leaching from the system. The factors influencing the fate of land-spread nutrients are presented in Section 4.6.

The effluent utilisation areas are used primarily for crop or pasture production. Effluent applied to land may be mixed with clean water where effluent salinity or nutrient concentrations are outside optimal ranges for particular crops or soil types. The method of effluent application affects the N volatilisation rate and the nutrient leaching risk. The primary drivers of nutrient losses from effluent application to land areas are discussed in Section 4.7.

To prevent nutrient losses from manure and effluent utilisation areas, it is important to quantify the mass of nutrients for management and to understand the inputs and outputs and the loss pathways. This report provides a review of literature on current processes, data on the quantities of nutrients involved and the nutrient pathways.

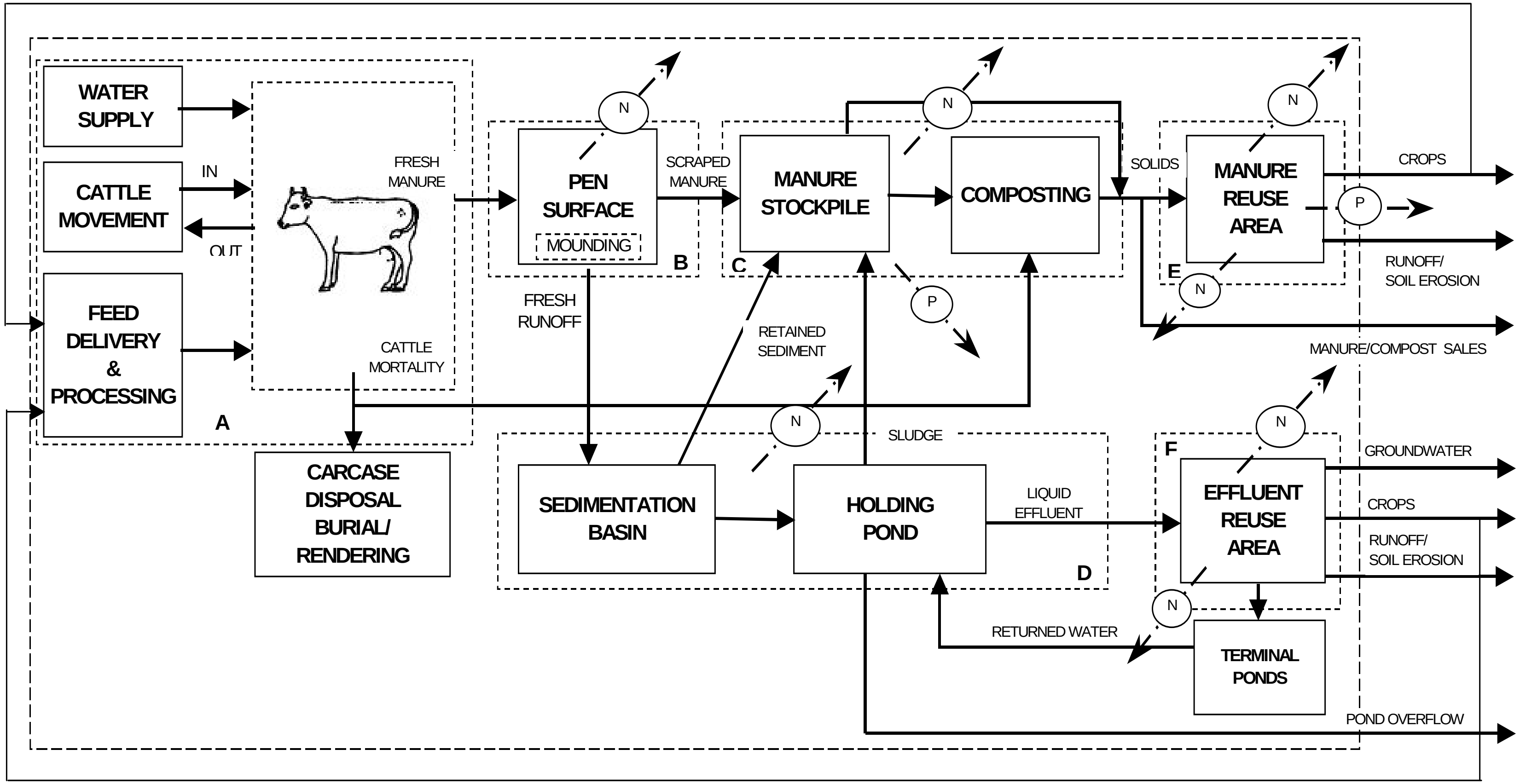

FIGURE 3 – CATTLE FEEDLOT SYSTEM

4.2 Cattle Nutrients

4.2.1 Cattle Composition

Cattle feedlots are designed to produce a consistently high quality product that meets specific market (domestic and export) specifications. The particular market types that a feedlot is targeting dictate the preferred cattle breeds and live weights at entry and the length of time (days on feed) cattle are fed. In Australia, typical market types include:

- Domestic (70-100 days).
- Korean (100 days).
- Japanese (100-120 days)
- Japanese (150-180 days).
- Japanese (220-300 days).
- Japanese long-fed (300+ days).

In Australia, some 30-35% of cattle are currently sold domestically, with 50-55% exported to Japan, 1-5% exported to Korea and 2.5-5% exported to other destinations.

Cattle entering feedlots range in liveweight according to the target market they will be fed for. For the domestic market, cattle traditionally enter feedlots at liveweights of around 300 kg. This compares to cattle fed for export markets that might enter the feedlot at 400-450 kg live weight.

The quantity of nutrients contained in cattle entering and leaving the feedlot depends upon the animals live weight and it’s chemical composition. Many factors influence the body composition of an animal including sex, breed, frame size, hormone implants and/or treatments. Maynard et al. (1979) found that, on a fat free basis, there is little difference in the chemical composition of mature animals, regardless of whether they are fat or thin. However, on a liveweight basis, fat has a large influence on the final composition as it contains few minerals thus diluting some of the total body ash components. A summary the mineral content of cattle at the start of the feeding cycle and during the growing / finishing stage taken from Van Sliedregt et al. (2000) is presented in Table 1.

TABLE 1 – MINERAL CONTENT OF CATTLE (g/kg OF LIVE WEIGHT)

	N	P	K	Salt	Ash
Start of Feeding	27	6.7	1.7	1.4	5.0
Grower/Finisher	24	7.0	1.8	1.5	4.0

Van Sliedregt et al. (2000)

Using the figures presented in Table 1 and assuming a steer being fed for the local trade enters the feedlot weighing 300 kg, it brings into the feedlot system some 8.1 kg N, 2 kg P and 0.5 kg K as part of its body mass. If the same steer leaves the feedlot 80 days later weighing 450 kg it will remove some 10.8 kg N, 3.15 kg P and 0.81 kg K as part of its body weight. By contrast, a steer being fed for 220-300 days for the Japanese market might enter the feedlot at a weight of 400 kg and leave weighing 750 kg. This steer would bring 10.8 kg N, 2.7 kg P and 0.68 kg K into the feedlot in its body mass and remove some 18 kg N, 5.25 kg P and 1.35 kg K when it leaves the feedlot for slaughter.

Epidemiology defines mortality rate as the (number of cattle die / number cattle entry / month) or (number cattle die / number cattle entry / year). Cattle mortality rates in Australian feedlots range from 0.2% (company raised/fed cattle) to 1.5% (custom feedlots). The primary cause of death in Australian feedlots is respiratory disease (95%), while other causes (transport, dystocia, sudden death and digestive) are responsible for less than 5% of the total mortalities (Doyle pers comm. 2005). Mortalities represent a nutrient flow from the feedlot system.

4.2.2 Feed and Water Consumed by Cattle

Feedlot diets are designed to achieve optimal rates of liveweight gain and meet specific meat quality targets cost effectively while also causing minimal digestive upset. To achieve these targets, diets are formulated to provide specific levels of metabolisable energy, crude protein, roughage, minerals and vitamins. The combination of commodities used in feedlot diets is determined by:

- The nutritive requirements of the cattle to meet these targets.
- The quality, composition and price of available commodities.

Commodities included in diets represent a nutrient input into the feedlot system, irrespective of their source. Typical requirements of N, P and K by cattle are presented in Table 2.

TABLE 2 – N, P AND K (g/kg DM) REQUIREMENTS IN CATTLE DIETS

	N	P	K
Beef cattle	1.9 – 2.3	1.8 –3.2	5.0

Source (National Research Council, 1996)

The N, P and K content of each feedlot diet is the summation of the N, P and K content of each individual ingredient. However the total nutrient input to the feedlot system also depends upon the quantity of each diet that is used. This depends upon the average dry matter (DM) feed intake of the cattle fed each diet and the number of cattle fed each diet. Factors influencing the DM feed intake of ruminants include weight, age, breed, sex, physiological state (i.e. pregnancy or lactation), frame size, body fatness, energy density of the diet, physical form of the diet and environmental factors such as heat or cold (van Sliedregt et al. 2000). In general, an animal requires some 2.2-3% of its liveweight as DM feed intake per day. Figure 4 shows a typical relationship between DM intake and days on feed for feedlot cattle (taken from van Sliedregt et al. (2000)). These data show that feed intake is reasonably constant with days on feed. This is contrary to previous assumptions used to predict manure production.

Of the water consumed by cattle, some is respired and some is excreted. Nutrients and minerals may be present in the water used (particularly where bore water is used) or added to water supplies to enhance animal growth. However, the quantities involved are minor and hence are not considered further in this report.

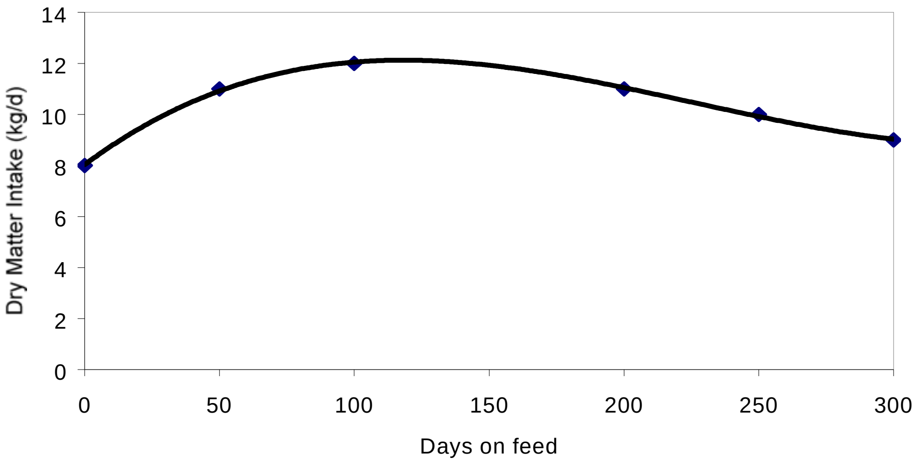

FIGURE 4 – RELATIONSHIP BETWEEN FEED INTAKE AND DAYS ON FEED

4.3 Pen Surface

4.3.1 Nutrient Excretion in Manure

Manure is the combination of faeces and urine. The N, P and K content of fresh feedlot cattle manure depends mainly upon the diet composition and the feed intake of the cattle.

Dietary modification provides the key to reducing nutrient excretions. For instance, proper balancing of diets to crude protein (CP) needs can greatly reduce N output. Van Horn et al. (1994) showed that balancing the rumen degradable and non-degradable protein could be expected to reduce N excretion by 15% in dairy cattle compared to cattle fed diets based on the National Research Council of the Academy of Sciences (NRC) (1989) CP standards. Erickson et al. (1998) reported similar findings when applying NRC (1996) requirements to balancing finishing steer diets. They fed a control diet containing 13.5% CP and 0.354% P and a diet balanced to NRC (1996) recommendations containing 11.5% CP and 0.22% P. Performance was similar between groups as was N and P retention. With reduced intake of N and P and similar nutrients retentions less N and P was excreted by the steers fed the balanced diet. Calculated N excretion was reduced from 0.5 lb/head/day to 0.42 lb/head/day (0.227 to 0.191 kg/head/day) and P excretion was reduced from 0.08 lb/head/day to 0.04 lb/head/day (0.036 to 0.018 kg/head/day) (Zehnder and Dicostanzo 1997). Morse (1989) and Tomlinson (1992) showed that the level of N and P excretion by dairy cows varies dramatically with the level of N and P intake and was predictable with equations based on daily N and P intake, DM intake and milk yield. In the case of beef cattle Neville (1977) cited by Church and Fontenot (1979) concluded that irrespective of the protein content of the diet (approx 16% N), N retention by cattle varied from 26.4-33.8% of intake. However, Varel et al. (1999) suggest that cattle retain less than 20% of their dietary N intake.

Sinclair (1997) found excretion of P in cattle faeces and urine was linearly related to P intake. Surveys (Watts et al. 1994; Shaver & Howard 1995) indicate that dairy and beef producers usually feed more dietary P than animals require. In a two year study conducted over consecutive summers, Erickson et al. (1998) showed that decreasing levels of P in the diet of steers from conventional levels of 0.4% down to 0.22-0.28% improved the efficiency of P use and decreased P excretion, with no effect on the animal's performance. Pigs fed diets containing 0.5% P compared to 0.6% P performed equally well with the pigs fed the lower level of P excreting 33% less of the mineral (Latimer & Pointillart 1993). In the Netherlands, P contained in pig diets is half the recommended level in an effort to comply with P output quotas (van Sliedregt et al. 1999). Hence, accumulating evidence suggests that alterations in diet formulations influence nutrient excretion rates by livestock.

Mass balance principles can be used to estimate the mass of nutrients in manure. Subtracting the mass of N, P and K of cattle leaving the feedlot from the mass of N, P and K entering the feedlot pens in cattle and feed gives the amount excreted by the cattle. The amount of N, P and K retained by the cattle is the difference between the mass of N, P and K within the bodies of the cattle on exit and the mass of N, P and K within the bodies of the cattle on entry. The critical factors in being able to use this approach for a particular feedlot over a given time period are an accurate knowledge of:

- The dry matter composition of the diets fed to the cattle.
- The feed intake of the cattle fed each diet.
- The number of cattle fed each diet.
- The liveweight of cattle entering the feedlot.
- The liveweight of cattle exiting the feedlot.
- The body composition of cattle entering the feedlot.
- The body composition of cattle leaving the feedlot.

From the previous example, the steer being fed for the local trade might:

- Bring into the feedlot system as incoming liveweight and feed a total of: 24.1 kg N, 22 kg P and 40.5 kg K. (Based on calculations of mass of nutrients imported in body weight in previous example (8.1 kg N, 2 kg P and 0.5 kg K as part of its body mass) and assuming an average DMI of 10 kg/day over 80 days and a feed composition of 2% N, 2.5% P and 5% K (producing 16 kg N, 20 kg P and 40 kg K entering the system in feed)).
- Remove from the feedlot system some 10.8 kg N, 3.15 kg P and 0.81 kg K in liveweight when it leaves the feedlot system (Based on calculations of mass of nutrients imported in body weight in previous example).
- Excrete some 13.3 kg N, 18.85 kg P and 39.69 kg K (the difference between incoming nutrients and outgoing nutrients).

The steer being fed for the Japanese market might:

- Bring into the feedlot system as liveweight and feed a total of: 75 kg N, 87.2 kg P and 169.7 kg K. (Based on calculations of mass of nutrients imported in body weight in previous example (10.8 kg N, 2.7 kg P and 0.7 kg K as part of its body mass) and assuming an average DMI of 13 kg/day over 260 days and a feed composition of 1.9% N, 2.5% P and 5% K (producing 64.2 kg N, 84.5 kg P and 169 kg K entering the system in feed)).

- Remove from the feedlot system some 18 kg N, 5.3 kg P and 1.4 kg K in liveweight when it leaves the feedlot system (Based on calculations of mass of nutrients imported in body weight in previous example).
- Excrete some 57 kg N, 81.9 kg P and 168.3 kg K (the difference between incoming nutrients and outgoing nutrients).

4.3.2 Nitrogen Losses from Pen Surfaces

From the time manure is voided from the animal until it is spread on land, the N content of the manure may change significantly as a result of gaseous losses. P & K are not present in gaseous forms and hence are not lost by volatilisation. Since modern feedlots have very low permeability pads and are located within controlled drainage areas, nutrients not lost by volatilisation either remain in the pen manure or move off the pad surface in pen runoff.

Manure decomposition begins after excretion with potentially 23-80% of the N in fresh manure lost very quickly (Muck & Richards 1983; Safley et al. 1985). Adriano et al. (1971) reported that nearly 50% of total N deposited on simulated feedlot surfaces was lost, which is consistent with the 40% loss rates they measured from corral surfaces. Gilbertson et al. (1971) recovered 42-55 % of estimated N excreted in the feedlot, indicating that the rest was lost through gaseous emissions and runoff. Bierman et al. (1996) indicated that researchers have estimated that as much as 50% of feed N is lost as volatilised NH_3, however other studies suggest 60-80% of the N excreted is normally lost through volatilisation of NH_3.

The sources of ammona (NH_3) gas in the feedlot are animal faeces and urine. Urine contains 60–80% of the total excreted N and 99% of the dry weight of urine is urea (Shi et al. 2001). Urea is hydrolysed by the enzyme urease, found in the faeces, to ammonium (NH_4) and bicarbonate ions. Hydrolysis occurs rapidly, with complete conversion of urea N to NH_4 possible within a matter of hours, depending on environmental conditions (Muck & Richards, 1980). Faecal N typically consists of 50% protein N and 50% NH_4. Mineralisation of faecal protein N occurs mainly through the activity of proteolytic and deaminative bacteria, initially hydrolysing proteins to peptides and amino acids and finally deamination to NH_4. This process occurs at a far slower rate than hydrolysis of urea (Varel et al. 1999). Koziel et al. (2005) measured NH_3 flux from fresh urine and faeces for almost 24 hours. The cumulative NH_3–N emissions from fresh faeces were 2.5% to 13.7% of NH_3–N for urine. Similarly, McGinn (2001) reports a 25000 head feedlot in Alberta, Canada, emitted 3445 kg NH_3 per day (0.138kg per animal). By default, MEDLI (Gardner et al. 1996) or BEEFBAL (McGahan et al. 2002) assumes that 40% of excreted N is contained in the urine, all of which volatilises on the day of excretion. It is assumed that the N remaining in the manure pad volatilises at a much slower rate – it is currently hardwired at a rate of 0.1% of the pad N each day. Similar rates have been measured in manure stockpiles.

The concentration and form of N in the diet can affect the quantity and form of N excreted by beef cattle (Cole et al. 2003). This in turn affects the nutrient pathways on the feedlot pad. McGinn et al. 2002 demonstrated a positive relationship between the level of dietary protein fed to feedlot cattle and the NH_4–N content of surface sampled pen manure. In chamber studies they found no significant difference between the NH_4–N content of manure and NH_3 emissions, although the lowest emission rate for surface manure coincided with the lowest protein level in the diet fed. However, Pandrangi et al. (2003) found that increasing the protein concentration in the diet increased potential

NH_3 emissions and the source of crude protein fed to cattle had little effect on NH_3 emissions. Similarly, Cole et al. (2003) conducted a trial with steers to determine the effects of dietary protein concentration and degradability on potential NH_3 emissions. Results suggest that as the dietary protein increased from 11.5% to 13%, potential daily NH_3 emissions increased by 60-225%, mainly because of increased urinary N excretion. However, if dietary protein concentrations fall to such a point that animal performance is adversely affected, then total NH_3 emissions could increase because the animals require more days on feed to reach market weight and specifications.

Temperature appears to play a significant role in N losses. Dewes (1996) evaluated temperature effects on N losses and concluded that almost all (99%) N was lost within four days when temperatures exceeded 40°C. Power et al. (1994) reported that little N may be lost with daily temperatures below 5 °C but 40-60% of total N contained in manure can be lost through NH_3 volatilisation at temperatures of 5 °C and 25°C. Bunton (1999) concluded that temperature was a major factor controlling the release of NH_3 into the atmosphere. Todd et al. (2005) measured NH_3 emissions from a commercial feedlot in Texas. They found that the NH_3–N emission rate averaged 4650 kg/d (55% of fed N) during summer and 2140 kg/d (27% of fed N) during winter. Gaseous N loss averaged 45% of fed N, so that most N was lost as NH_3 during summer, and NH_3 comprised about 60% of gaseous loss during winter. However, Baek et al. (2003) measured manure pack moisture content, pH, and total Kjeldahl N (TKN) daily over a two week period in summer at a Texas feedlot and found that manure pack temperature and TKN were only weakly correlated with NH_3–N flux. Koziel et al. (2004) investigated ambient NH_3 and H_2S concentrations in the air around a 50,000 head feedlot in Texas, USA, in spring, winter and autumn. The highest NH_3 emissions were recorded during spring followed by autumn. The NH_3 and H_2S exhibited daily patterns with two local maximums in the early afternoon and evening hours, with the lowest concentrations recorded during the night (Koziel et al. 2004).

Strategies to minimise NH_3 emissions should include the minimisation of N excretion to manure and also NH_3 formation and volatilisation. Feedlot operators can also minimise NH_3 emissions using a range of manure management and treatment methods and soil amendment techniques (Shi et al. 2001).

Pen cleaning frequency affects the rate of N loss, with more frequent cleaning reducing N losses from the feedlot pad. Erickson et al. 2003 compared pens cleaned monthly with those cleaned after a 166 day summer feeding period. They found that more frequent cleaning reduced N losses by 66.2% per steer.

The addition of a carbon source to pen surfaces or compost (Dewes 1996, Erickson et al. 2003), decreasing diet digestibility and minimising dietary protein (Erickson & Klopfenstein 2001) also reduces N losses. However, decreasing diet digestibility adversely affects animal performance (Erickson & Klopfenstein 2001, Erickson et al. 2003). Erickson et al. (2003) investigated the effect of feeding bran or adding sawdust to pens on N dynamics. Feeding bran produced higher N excretion rates. N losses from the feed yard ranged from 27–49 % of total N excreted. Less than 5 % of excreted N was lost via runoff. Over the winter/spring feeding bran and putting sawdust over the pen surface reduced N losses (29.1% and 26.8% of excreted N was lost, respectively) compared with the control (49.4% of excrete N was lost). When yearlings were fed over summer the benefits of feeding bran or using sawdust were minimal, with 56.4% N loss from the bran treatment and 64.8% N loss from the sawdust treatment compared with 62.2% from the control. It appears that N losses by volatilisation are very rapid in summer.

Todd et al. (2005) found that feeding bran reduced N losses from 49.0% to 29.5% of N excreted if pens were cleaned monthly rather than at the end of a 140 day feeding period. If manure was allowed to accumulate on pen surfaces and was removed at the end of the feeding period, diet had no effect on N in manure and subsequent N losses. Cleaning pens monthly produced manure containing 66.2% more N than if the manure was removed at the end of the feeding period. If manure was not regularly harvested, more N is exposed and available for volatilisation (Erickson et al. 2003).

Numerous additives aimed at reducing NH_3 volatilisation losses have been investigated over the last three decades. These can be categorised into one of five groups according to their modes of action: digestive additives, acidifying additives, adsorbents, urease inhibitors and saponins from Mo-have yucca (*Yucca schidigera* Roezl ex Ortgies) (McCrory & Hobbs 2001). Shi et al. (2001) investigated the efficacy of amendments in reducing NH_3 emissions from beef cattle feedlots. All amendments reduced NH_3 emissions, with the two aluminium sulphate treatments being the most effective, reducing the 21 day cumulative NH_3 emissions by 91.5% and 98.3%.

Varel et al. (1999) evaluated two urease inhibitors: cyclohexlposphoric triamide (CHPT) and N-(n-butyl) thiophosphoric triamide (NBPT) designed to inhibit the urease enzyme which converts urea to NH3. They found that both products increased the urea content of pen manure. However once the treatments were stopped, the urea concentration in manure decreased. However, Koziel et al. (2005) found no significant differences in NH_3 fluxes between NBPT urease inhibitor and non-treated pens. The effectiveness of additives, particularly commercially available products, in reducing NH_3 emissions from livestock waste continues to be the subject of debate (Ritter 1989; Zhu et al. 1997; Parker et al. 2005).

For Australian conditions the percentage of total N volatilised from fresh manure and from the pen surface could range from 60% to almost 100%. Some 60-80% of all N is in the urine and most of this is likely to be rapidly lost. Additionally some of the faecal N would be lost. **Hence, the estimated N loss rate from the feedlot pad is 80%.**

4.4 Manure Stockpile/Composting

Manure collected from Australian feedlots is commonly stored in compacted stockpiles or composted windrows (Kuhlman 1992; Powell 1996). Temperature, moisture, pH and C:N ratio are important determinants of the amount of N lost from manure (Eghball & Power 1994). Stockpiling allows the gaseous loss of N, an increase in NH_4 concentration (Kirchmann 1991) and leaching of other nutrients (McCalla et al. 1977; Powell 1996). The rate of N loss from the stockpile is slightly higher than the DM loss rate (Powell 1994). Power et al. (1994) estimated N losses through volatilisation of up to 25% of the N in manure stored in a stockpile.

Alternatively, manure stored under predominantly aerobic conditions (or actively composted) produces greater water losses (Powell 1994) and decomposition of cellulose and fibre (Follett & Croissant 1990). Eghball and Power (1994) reported N losses (20–40%) during composting and small P losses due entirely to runoff from the compost piles. When Eghball et al. (1997) researched N losses from outdoor composting in Nebraska over three consecutive summers they found that N losses ranged from 19% to 42% with the loss rate depending on the initial N content. NH_3 volatilisation accounted for >92% of the N loss whilst combined nitrate and NH_3 runoff loss was <0.5%. Erickson et al. (2003) showed that the addition of carbon to manure before composting increased N recovery by reducing N loss through NH_3 volatilisation.

Table 3 presents data for the moisture, N and P content of pen fresh and stockpiled manure. It shows that the moisture and N content is significantly lower in stockpiled manure while the P content is higher.

TABLE 3 – PEN FRESH AND STOCKPILED MANURES FROM SOUTHERN QUEENSLAND FEEDLOTS (ADAPTED FROM LOTT 1995)

	Pen Fresh	Stockpiled
Number of samples	40	53
Moisture %	34	24
Total N %	2.37	2.03
Total P %	0.75	0.83

Predictions of N loss rates from feedlot pads using BEEFBAL (McGahan et al. 2002) indicate that about 3% of the N remaining in the manure on the pad after volatilisation losses will be exported to the pond. The balance would be available for harvesting. N volatilisation rates from feedlot stockpiles or composting areas are typically 15-40%. A loss rate in the order of 25% would be expected under Australian conditions. Some 3% of the P and 8% of the K would be exported to the settling basin and retention pond in runoff. Hence some 97% of excreted P and 92% of excreted K would be found in the harvested manure.

4.5 Sediment Basin/Holding Ponds

The N, P and K in manure remaining on the feedlot pad after volatilisation losses (for N) are taken into account. Firstly it may be harvested during pen cleaning and taken to a stockpile or composing areas. Secondly it may be removed in stormwater runoff from the feedlot surfaces and the surrounding balance areas (hard, soft and other areas). The concentration and quantity of nutrients contained in effluent is affected by diet, pen cleaning frequency, evaporation and rainfall patterns. Because different pens may be used for cattle for different markets and may have different manure harvesting programs, the depth of pen manure can vary between pens and consequently the quality and quantity of runoff contributed by each pen also varies. Thus, the overall runoff characteristics from the production area are derived from the cumulative totals of runoff and eroded solids, nutrients and salts generated by each production pen.

Most Australian feedlots collect effluent from the pens and surrounding hard surface areas via designated impermeable drainage lines. These direct the effluent to a sedimentation basin or basins and then to a pond or ponds which allow solids and particulate matter to settle out. The last pond, commonly referred to as the holding pond, usually contains effluent containing less than 5% solids.

The efficacy of the sedimentation basin plays a crucial role in the composition of the holding pond effluent. Between 35% and 75% of solids eroded from the pen surface may be retained in the sedimentation basin (Lott et al. 1994). Madden and Dornbush (1971) estimated potential N, P and K reductions of around 35%, which are much lower than Lorimor et al. (1995). The N and P flowing into the holding pond are partitioned between the sludge and the supernatant. The default fractions remaining in suspension are 0.7 and 0.65 respectively (Madden & Dornbush 1971). Sweeten and Wolfe (1994) found that well maintained settling ponds had a total N removal efficiency of 14-24%. Culley and Phillips (1989) observed that liquid storage facilities can lose approximately 33% of that N by volatilisation.

Lott (1995) states that evaporation has a significant effect on the water balance in holding ponds. Linderman and Ellis (1978) found that nutrient concentrations increase over time because of this, whilst the processes of sedimentation and volatilisation reduce P and N levels, respectively, thus affecting their concentration in the effluent. Atzeni et al. (2001) highlighted the rate of N volatilisation as an area requiring further research. Mass balance modelling suggests it has to be very low in order to achieve average pond N concentrations within the range of observed values.

Depending on the moisture content and animal species the NH_3 + NH_4 in liquid animal manure can account for 28-85% of the TKN (Chastain et al. 2001; Montes 2002). N loss through NH_3 volatilisation is most sensitive to pond surface area, whilst the P, K and total dissolved salt concentrations in the supernatant are most affected by the amount of evaporation relative to rainfall.

Gilbertson et al. (1971) found that at high rainfall sites the salt concentration of feedlot runoff was lower than that of runoff derived from arid sites. However, as runoff increases, so to does sediment transport (Reddel & Wise 1972) therefore increasing concentrations of some nutrients, for instance P. Manges et al. (1971) also concluded that as runoff rates increased, N and P concentrations in runoff decreased. They studied the effect of two rainfall events separated by a short period of time and found that the concentration of N and P in the runoff was higher after the second event because wetting from the first event and raindrop impact caused manure particles to go into suspension.

Feedlot operators in Australia like to minimise the risk of odour by maintaining only a thin layer of compacted manure above the clay and gravel. As a result, little water is stored in the manure pack. Lott (1997) concluded that more rainfall appears as runoff than previously reported by Gilbertson & Nienaber (1973). However, there is conjecture about the rate of pad evaporation, particularly after wetting and subsequent pugging of the pad. However, it is clear that the pen evaporation must be allowed to exceed pan evaporation to some degree to account for the anecdotal evidence that the manure pad dries out rapidly even in periods of low evaporation – possibly due to enhanced evaporation because of cattle disturbing the pen surface.

Gilbertson et al. (1970) reported N and P losses in runoff from feedlot areas and found that 8% of total N was diverted to liquid runoff in summer compared to 40% in winter. However, this work is now very dated and unlikely to accurately reflect the current situation because of improvements in feedlot design standards and manure management. This means that there is far less manure available for export to the ponds. Predictions of N loss rates from feedlot pads using BEEFBAL (McGahan et al 2002) indicate that about 3% of the N remaining on the feedlot pad after volatilisation losses is exported to the settling basin and retention pond in runoff. Similarly, P losses were 4% under unfrozen conditions, increasing to about 20% in the winter. Gilbertson et al. (1970) found that P transport as a result of rainfall-runoff was not affected by stocking rate or feedlot slope. However, winter conditions produced four to seven times more P runoff than summer conditions.

Feedlot effluent characteristics vary between Australia and the USA due to a combination of factors, including:

- Increased runoff.
- Climatic factors (rainfall and evaporation).
- Pen management allowing greater mineralisation of manure on the pen surface.

Generally, effluent produced in Australia has lower concentrations of N (Table 4) and the P and K content is similar to that of effluent derived from feedlots in the US (S. Lott pers. comm.). In some localities this is tempered by high rainfall significantly diluting the effluent stored in ponds.

TABLE 4 – EFFLUENT COMPOSITION FOR US AND AUSTRALIAN FEEDLOTS (THE RANGE IS SHOWN IN PARENTHESES).

Component	Concentration	
	United States	Australia
Total N (mg/L)	721 (286-1155)	480 (50-500)
Total P (mg/L)	104 (26-440)	105 (3-142)
Total K (mg/L)	2370 (985-9102)	2100 (28-6003)
Electrical Conductivity	-	1 - 10 dS/cm

Reported values for runoff quality in holding ponds show a range that is both broad and variable within and between feedlots and hence is difficult to predict. A poor understanding of N volatilisation from the pen to the holding pond further confounds the N situation.

Predictions of N loss rates from feedlot pads using BEEFBAL (McGahan et al 2002) indicate that about 3% of the N remaining in the manure after volatilisation losses is exported to the settling basin and retention pond in runoff. Some 23.5% of this might be partitioned to sludge while the balance will remain in the supernatant. The small amount of research data that is available suggest that N volatilisation from the supernatant in the ponds is likely to be in the order of 35%. BEEFBAL estimates suggest that 3% of the excreted P and some 8% of the excreted K is exported to the settling basin and retention pond in runoff. It is expected that some 90-95% of the P and 5-10% of the K would deposit to the sludge with the balance remaining in the supernatant.

4.6 Manure/Compost Utilisation

Fresh pen, stockpiled or composted manures are typically spread on land areas designated for crop or pasture production. These areas may be on or off-farm. Manure going off-farm may also be used to produce compost and other soil amendments. Off-farm transfers of manure export all of the nutrients contained in the manure from the feedlot system. When the manure is spread on land on-farm the most significant export from the feedlot system is through harvesting of crops and pastures grown on the reuse areas. (The nutrients contained in harvested feed are considered to be an export from the system even if they are used to produce feed for the feedlot. In this case, the nutrients in the feed are accounted for as an input to the system). However, nitrogen is also lost through NH_3 volatilisation from the manure during and after spreading.

The manure is used as a substitute for the application of inorganic fertilisers within the production system – that is, the manure is applied to areas that would normally be fertilised anyway, and the manure is applied at rates calculated to provide a long-term balance of nutrients applied and removed from the application area. Reuse areas need to be managed to prevent losses to the environment under standard operating conditions. Consequently, this report only considers the losses occurring during the actual manure / compost spreading. Any losses occurring after this time are assumed to be a normal part of the operation of the crop / pasture system. Since P and K are not subject to gaseous losses, the focus of this section is N emissions.

Numerous methods are used to spread and incorporate manure and N loss varies widely depending on the method used. The most common method is broadcast spreading. The main losses during this phase of manure handling are for N, chiefly via NH_3 volatilisation.

The rate and amount of NH_3 loss is related to weather conditions and the characteristics of the manure and the soil to which it is applied. N losses increase exponentially with temperature (Sommer et al. 1991) and up to a wind speed of 2.5m/s (Rotz 2004). Stewart (1970) showed that both nitrification and NH_3 volatilisation was lower at higher levels of pH. Peters and Reddell (1976) reported that 10% of the total N applied as cattle manure was volatilised from a soil with a pH 7.5 increasing to a 20% volatilisation loss when the soil pH was 12. At higher pH levels there is a greater degree of cation saturation on the exchange complex thus less adsorption of NH_4^+. As well, the presence of OH^- favours the volatilisation of NH_4^+.

Peoples et al. (1995) reported that NH_3 losses from animal wastes ranged from 0% to >50% of the N applied to various cropping systems and from 9% to 33% of the N applied to grasslands. Adriano et al. (1971) investigated volatilisation loss of NH_4^+ from urine, faeces, a urine/faeces mixture and a urine/faeces/soil mixture. Results showed the combination of urine and faeces produced three times the amount of NH_4^+ volatilisation than either component alone, representing 99% of the urinary N added. By comparison, about 69% of the urinary N from the urine/faeces/soil mix was volatilised.

Nitrification and denitrification processes in the soil cause N emissions, mainly as N_2O and N_2. The amount of denitrification that occurs is a function of the amount of total N and available C in the soil and the anaerobic conditions in the soil (Carey et al. 1997). Although total denitrification losses can be large (Carey et al. 1997), limited data indicates that N_2O loss is normally less than 2% of the total N applied (Weslien et al. 1998; Sherlock et al. 2002 In Rotz 2004). After 21 annual applications of feedlot manure to soil in southern Alberta, Chang et al. (1998) reported that annual emissions of N_2O increased with increasing manure application rate. The rate of N_2O emission could not be related to an environmental factor as the rate of emission is controlled by rate of production and diffusion. Emissions were thought to reflect the accumulation of NO_3^- and organic matter from repeated manuring.

Rotz (2004) suggests that N losses as a percentage of the total N spread comprise some: 20% (8–60%) as NH3, 1–25% as NO_3 and <1–4% as N_2O. N can be lost through surface runoff but this is generally quite a small loss pathway (<3% up to 10%) and not applicable here since there would be some losses from the use of inorganic fertilisers rather than manure. Surface spreading of manure without soil incorporation often ensures the loss of all remaining inorganic N (typically 20-40% of remaining N). Rapid incorporation decreased this loss by at least 50% (Rotz 2004). Svensson (1994) found that N losses through volatilisation may be reduced by up to 98% through the immediate incorporation of the manure into the soil.

Research suggests that an N loss rate in the order of 20% of N applied could be expected under Australian conditions. P and K are not subject to gaseous losses.

4.7 Effluent Reuse

Effluent is sometimes too saline or concentrated to irrigate without supplementation or dilution. The quantity of water used for supplementation or dilution varies widely between feedlots depending upon the ‘strength’ of the effluent being irrigated and the area to which it is applied.

In the USA, Canada and Europe regulatory agencies have either prohibited the use of irrigation as a land application method or are considering its prohibition to reduce NH_3 emissions from agriculture (Chastain & Montes 2004). The NH_3 losses from irrigation occur over a 1 to 4 day period following irrigation (Meisinger & Jokela 2000; Montes 2002).

Many studies have reported volatilisation losses of 10–18 % during irrigation of liquid swine manure (Westermann et al. 1995; Safley et al. 1992). However Welsh (1973) concluded that volatilisation losses during irrigation of dairy slurry, liquid swine manure and effluent from an oxidation ditch were insignificant. Chastain and Montes (2004) report three studies (Montes 2002; Safely et al. 1992 and Welsh 1973) that aimed to quantify NH_3 losses but conclusions were inconclusive.

In a literature summary of NH_3 volatilisation losses during irrigation Chastain and Montes (2004) found that NH_3 losses ranged from 2.5% to 13%. Chastain and Montes (2004) conducted an assessment of NH_3 volatilisation losses during sprinkler irrigation. Data in literature included losses from travelling gun, centre pivot and impact sprinkler irrigation of dairy, swine, and beef manure. The concentration of NH_3–N + NH_4–N collected on the ground did not differ from that collected from irrigated wastewater indicating that there were no NH_3–N + NH_4–N volatilisation losses. The researchers further concluded that evaporation and drift were not major factors in NH_3–N + NH_4–N loss.

Research shows that volatilisation losses during irrigation typically range from 2.5-18%. Hence, it is assumed that 15% of the N in effluent is lost during irrigation. P and K are not subject to gaseous losses.

5 Data Collection and Analysis

5.1 Survey Data

As part of the FLOT.328 project, a detailed survey of feedlot inputs and outputs was undertaken to collect the data required for the life cycle inventory (see Section 3.4). The survey was conducted on-line.

For this report, the relevant data collected included:

1. Data on the number of incoming and outgoing cattle, intake and sale weights, dressing percentages, DM intake, days on feed and other parameters that allow HSCW gain to be estimated for two years (2002 & 2004).

- Total feed commodity and supplement usage in 2002 and 2004.
- Manure removed from the feedlot area, chemical composition and pen surface management, including cleaning frequency.
- Effluent storage capacity and typical concentrations.

Nutrient flows were broken up by cattle in and out, pen surface, manure stockpile, sedimentation/holding pond, manure utilisation area and effluent utilisation area for two years (2002 & 2004).

Most feedlots were able to provide good-quality data on incoming and outgoing cattle numbers and production. Hence, it was possible to estimate nutrient quantity in terms of HSCW gain (kg).

5.2 Data Analysis

After data was entered into the survey by lot feeders, the data was entered into a large Feedlot System Analysis Model spreadsheet (FSA Model) where various parameters were calculated and data quality checks were undertaken. Where anomalous data was detected, the participating feedlot was contacted and the data was examined in more detail.

However, in some cases there still remained a mismatch between the mean number of cattle on hand estimated by the FSA model and that given in the survey. In most cases this was due to the yearly cattle number data and summary mean cattle on hand entered into the survey which does not capture monthly fluctuations. The following discussion outlines potential errors in the data.

Firstly, HSCW gain was calculated from the survey data of cattle numbers in, entry weight, total liveweight in, cattle numbers out, exit weight and total liveweight out and mortality numbers. Secondly, HSCW gain was estimated by the spreadsheet model from the model estimated number of cattle in, entry weight from survey and model estimated number of cattle out, exit weight from survey and mortality numbers from survey. In both cases, an estimate of dressing percentage in and out was required.

The mean number of cattle on hand on the 1st and last day of each survey year was required to be input into the survey. The average of this was used as the survey mean number of cattle on hand. This was compared with the FSA Model estimated mean number of cattle on hand and the difference presented in Figure 5 and Figure 6 from 2002 and 2004 respectively.

Figure 5 and Figure 6 illustrate the percentage difference between the HSCW gain calculated from the survey data and estimated from the spreadsheet model and the difference between mean number of cattle on hand input into the survey and that estimated from the spreadsheet model for the 2002 and 2004 calendar years. A positive difference results from the FSA Model underestimating values and similarly a negative difference results from the model overestimating values when compared with survey data.

Figure 5 and Figure 6 illustrate that feedlots were able to provide very good estimates of total cattle numbers in and out and total liveweight in and out, therefore errors between HSCW gain as calculated from survey data and that estimated from the FSA Model are typically less than 1%, with the exception of Feedlot 3 and Feedlot 6 in 2002. Hence, results standardised per kg HSCW gain have small inherent errors, with the exception of Feedlot 3 and 6 in 2002.

Errors were found between the mean number of cattle on hand as determined from survey data and that estimated from the FSA Model across all feedlots. Errors ranged from –9% to 24% and –20 to 55% for the 2002 and 2004 survey years respectively. Hence, results calculated from or based on mean number of cattle on hand potentially have large inherent errors.

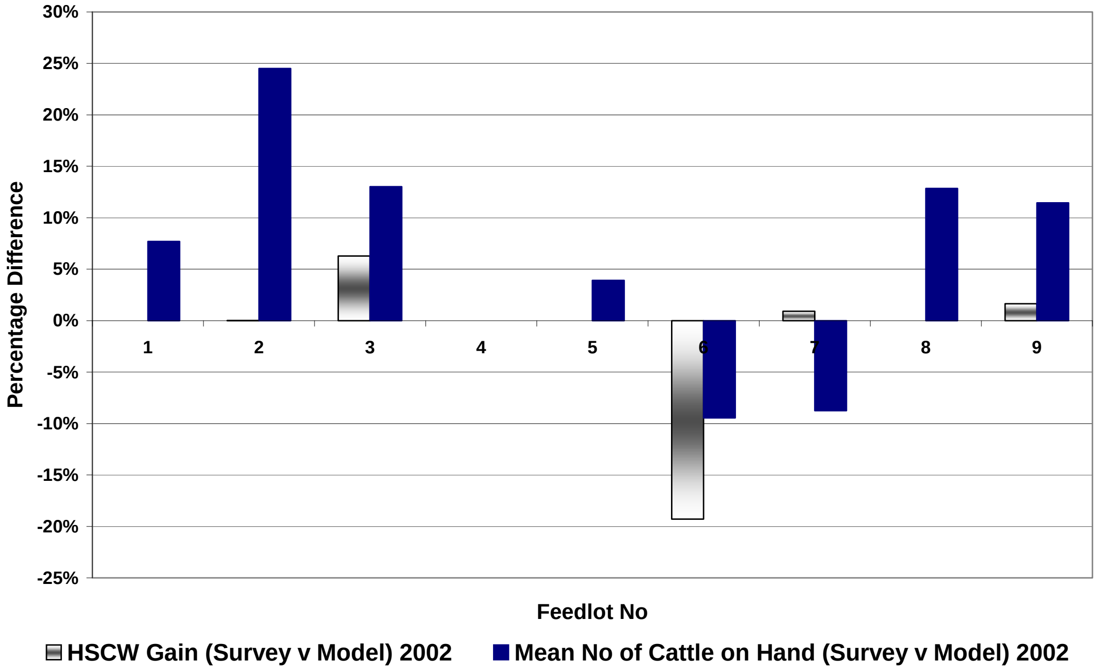

FIGURE 5 – PERCENTAGE DIFFERENCE BETWEEN SURVEY DATA AND MODEL ESTIMATION FOR 2002 SURVEY YEAR.

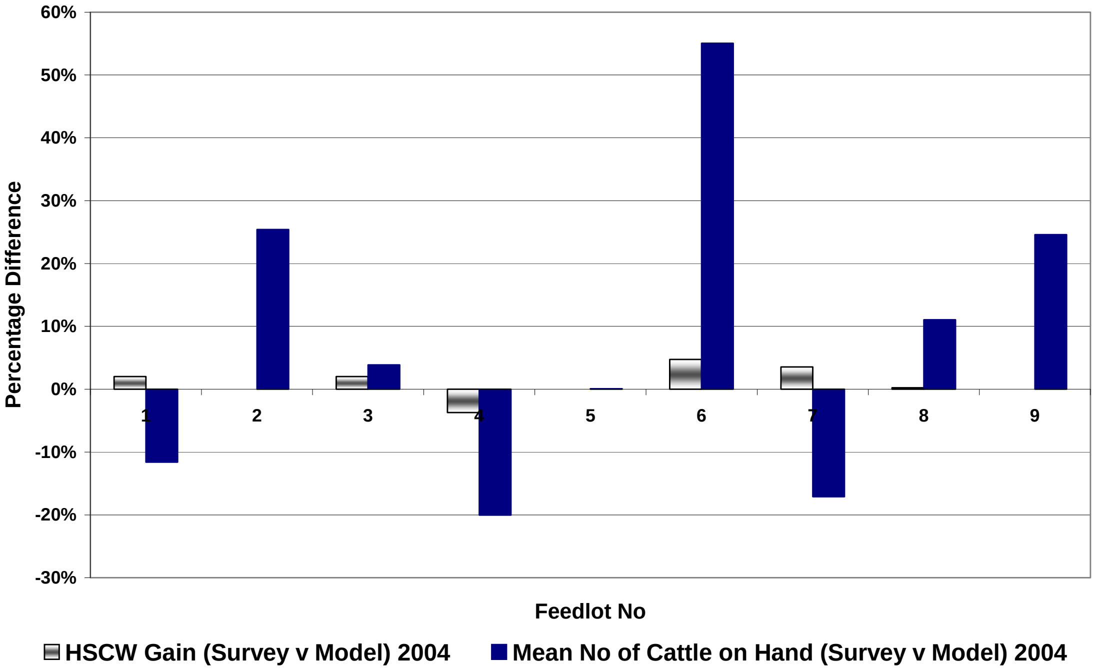

FIGURE 6 – PERCENTAGE DIFFERENCE BETWEEN SURVEY DATA AND MODEL ESTIMATION FOR 2004 SURVEY YEAR.

6 Results and Discussion

6.1 Mass of Manure Produced

The mass of manure removed from the pens, taken from the stockpile area and composted or sold off-farm was required to be input into the survey. These parameters were then standardised per kg HSCW gain. Feedlots use various manure management systems including mounding in pens before stockpiling, stockpiling and various degrees of composting.

Figure 7 and Figure 8 illustrate the mass of manure removed from the pens and stockpile area and the quantity of manure and/or compost sold off-farm per kg of HSCW gain for the 2002 and 2004 calendar years. Feedlots 3 and 6 could not provide the mass of manure removed from pens. No data was available from Feedlot 4 in 2002.

Figure 7 shows that annual mass of manure removed from the pens ranges from 4.8 kg/kg HSCW gain to 10.2 kg/kg HSCW gain with a median value of 6.2 kg/kg HSCW gain for the 2002 survey year. Manure removed from pens would depend on a number of factors including market type, environmental factors and manure treatment within the pen (viz mounding). Feedlot 5 is the only feedlot to mound manure in the pen before stockpiling.

Figure 8 shows a range of 4.0 – 12.5 kg /HSCW gain for annual mass of manure removed from the pens with a median value of 5 kg/kg HSCW gain. These levels are less than 2002 levels.

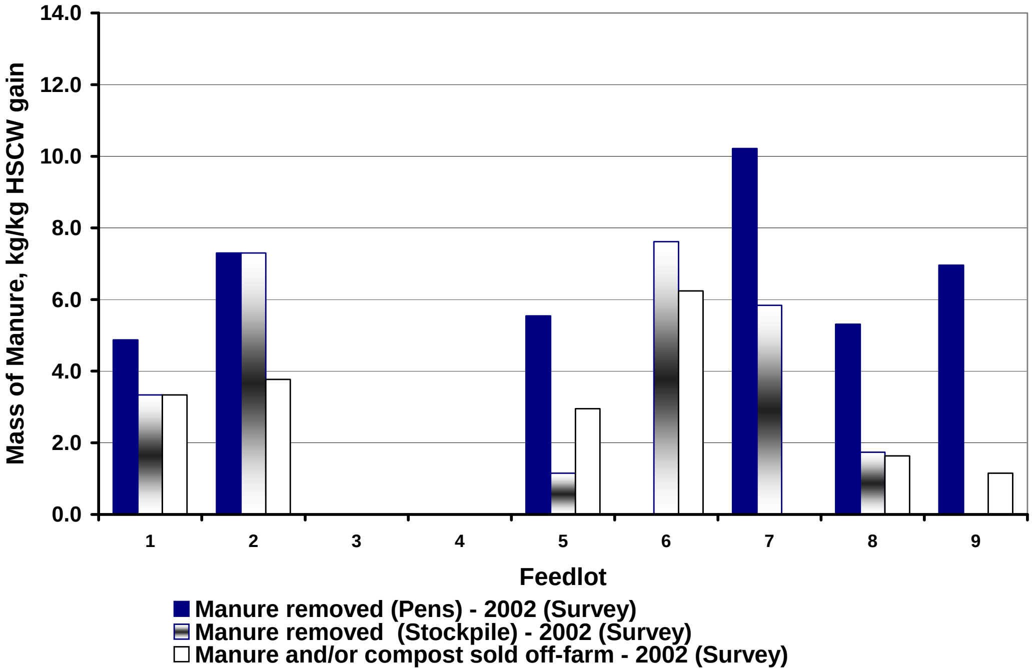

FIGURE 7 – MASS OF MANURE REMOVED FROM PENS AND STOCKPILE AREA FOR THE 2002 SURVEY YEAR.

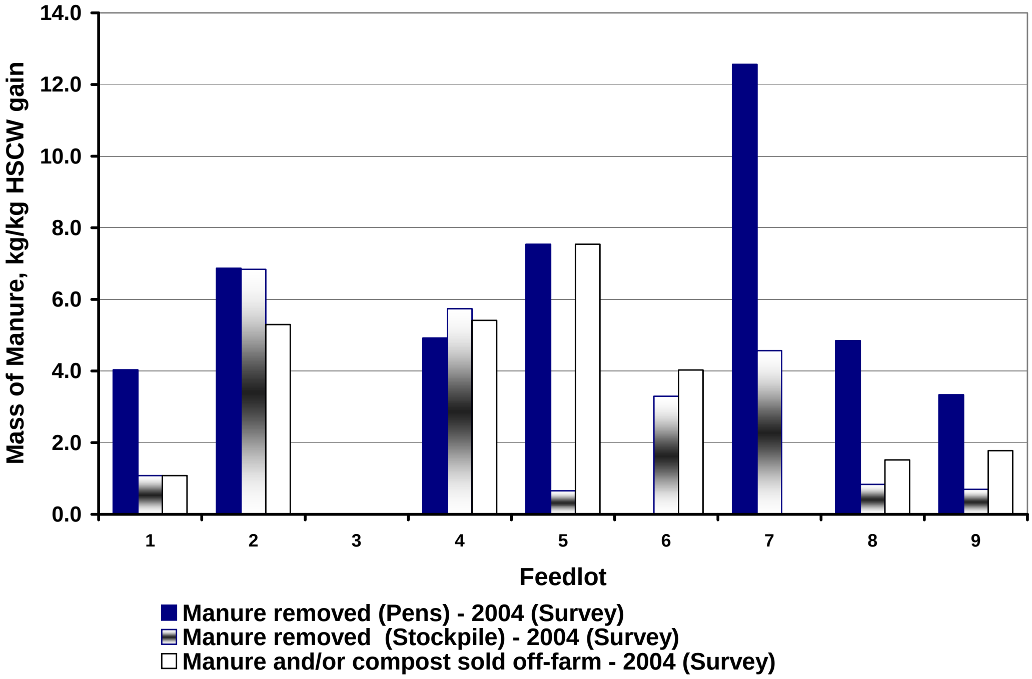

FIGURE 8 – MASS OF MANURE REMOVED FROM PENS AND STOCKPILE AREA FOR THE 2004 SURVEY YEAR.

6.2 Nutrient Inputs/Outputs

N, P and K input levels were estimated from the survey values for total liveweight in, water intake, quantity of feed fed and their corresponding nutrient analyses. N, P and K output levels were estimated from the survey values for total liveweight out, mortalities and their corresponding nutrient analyses. Using mass balance, the nutrient levels remaining in manure could be estimated. The nutrients enter the system via cattle, feed and water. They leave the system via cattle, mortalities and in the manure. The quantity of nutrients is expressed as kg nutrient/kg HSCW gain.

6.2.1 N Inputs

Figure 9 and Figure 10 present results for N input levels from the nine surveyed feedlots for the 2002 and 2004 survey years respectively. The input contribution from N in water represented less than 0.003 kg/kg HSCW gain of the total N input, a very minor contribution when compared with incoming cattle and feed.

Total N input ranges from 0.24 kg/kg HSCW gain to 0.38 kg/kg HSCW gain for the nine surveyed feedlots during the 2002 survey year. This comprises a component from incoming cattle (0.05-0.12 kg/kg HSCW gain) and feed intake (0.15-0.33 kg/kg HSCW gain). The contribution of N from feed ranges from 60% to 87% of the total N input.

For 2004, total N input ranges from 0.24-0.4 kg/kg HSCW gain for the nine surveyed feedlots and are similar to 2002 input levels. The N input from incoming cattle ranged from 0.06-0.12 kg/kg HSCW gain, with feed intake contributing 0.15-0.34 kg/kg HSCW gain. The contribution of N from feed ranges from 64-84% of the total N input.

The quantity of N required to produce a kilogram of HSCW gain for Feedlot 2 is 50% higher than for Feedlots 3, 4, 5, 7 & 8. Feedlots 2, 6 & 9 predominantly feed cattle for >150 days.

The level of N contained in individual diet ingredients is also a source of variation between feedlots. Feedlots use various grain and roughage types depending on availability, target diet nutrient composition and cost.

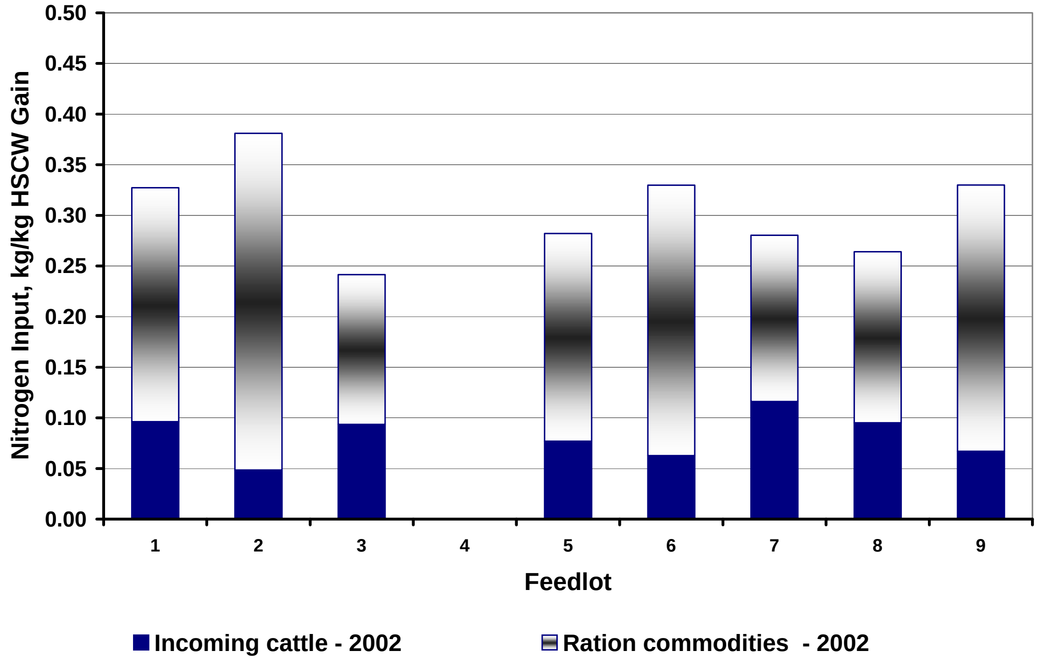

FIGURE 9 – N LEVELS IN INCOMING CATTLE AND FEED FOR 2002 SURVEY YEAR.

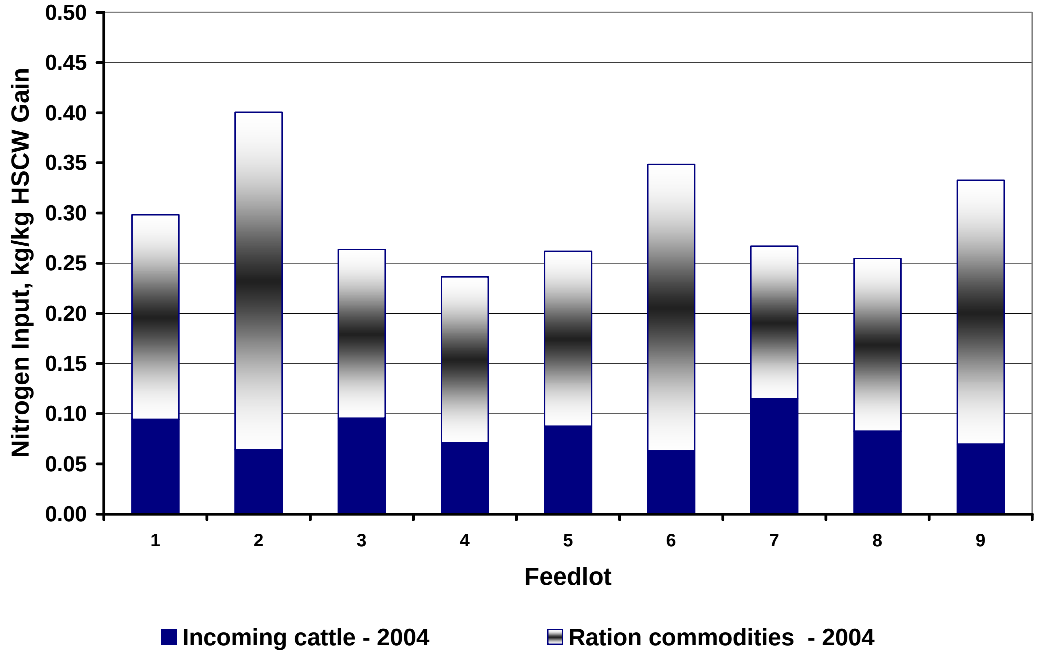

FIGURE 10 – N LEVELS IN INCOMING CATTLE AND FEED FOR 2004 SURVEY YEAR.

6.2.2 N Outputs

Figure 11 and Figure 12 present results on N output levels from the nine surveyed feedlots for the 2002 and 2004 survey years respectively. The N leaving the system in mortalities represented less than 0.003 kg/kg HSCW gain of the total N output, a very minor contribution when compared with outgoing cattle and manure.

Total N output ranges from 0.24-0.38 kg/kg HSCW gain for the nine surveyed feedlots during the 2002 survey year. This comprises a component from outgoing cattle (0.08-0.13 kg/kg HSCW gain) and manure (0.13-0.3 kg/kg HSCW gain). Hence, most N output is contained in manure (50–80 %).

For 2004, total N output ranges from 0.24 kg/kg HSCW gain to 0.4 kg/kg HSCW gain for the nine surveyed feedlots, which is similar to 2002 output levels. The N component in outgoing cattle ranged from 0.09 kg/kg HSCW gain to 0.13 kg/kg HSCW gain, with manure containing 0.13-0.3 kg/kg HSCW gain.

Levels of N in outgoing cattle were similar across all feedlots in 2004, with a slight variation found in the 2002 data. N variation in manure seems to be related to the composition of the markets that feedlots are feeding for, with the feedlots with long-fed cattle generally having a higher N output in the manure.

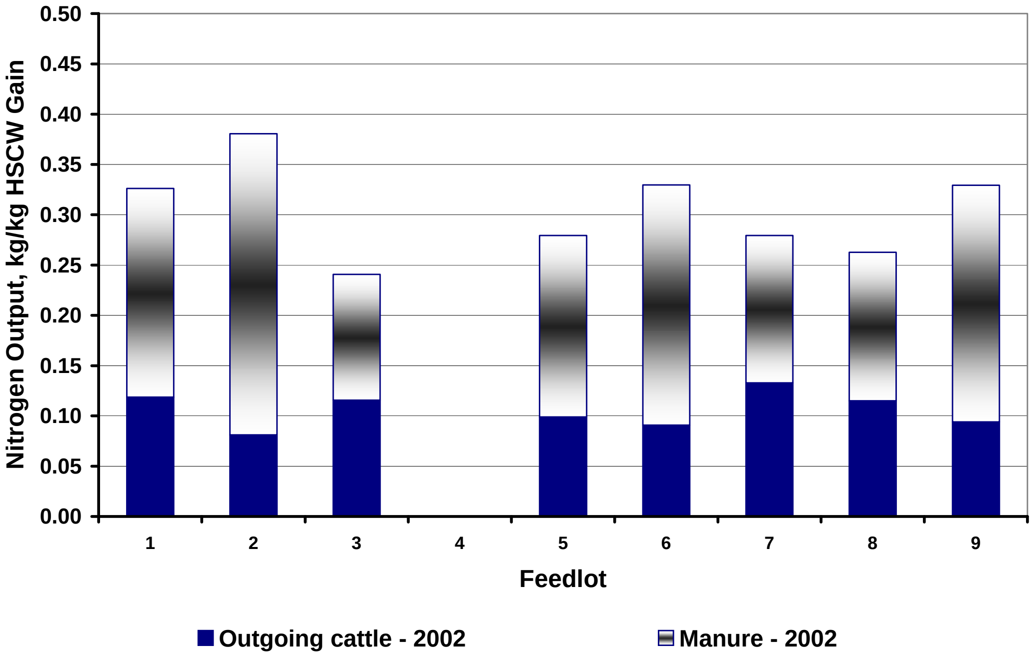

FIGURE 11 – OUTGOING N LEVELS IN CATTLE AND MANURE FOR 2002 SURVEY YEAR.

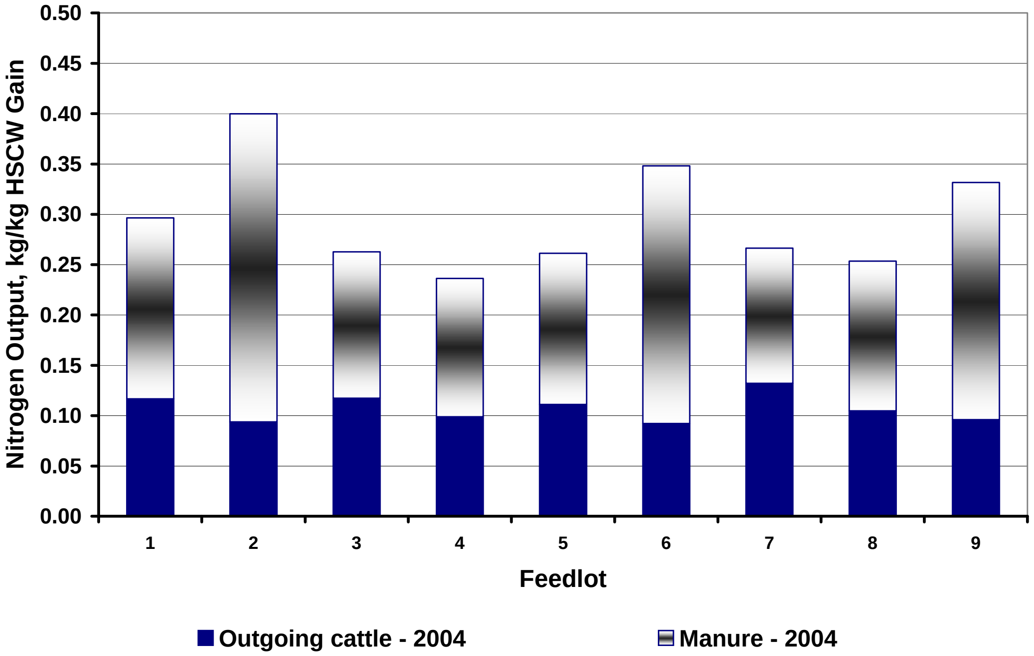

FIGURE 12 – OUTGOING N LEVELS IN CATTLE AND MANURE FOR 2004 SURVEY YEAR.

Corresponding with higher N input levels, Feedlots 2, 6 & 9 have higher N excretion levels than Feedlots 3, 4, 5, 7 & 8. N leaving the system in cattle is marginally higher per kg HSCW gain than N entering the system in cattle as it is assumed in the model that incoming cattle have a lower N content.

6.2.3 Fate of Manure N

Figure 13 and Figure 14 illustrates the fate of N contained in manure from the nine surveyed feedlots for the 2002 and 2004 survey years respectively. No data was available from Feedlot 4 in 2002. Three possible pathways exist for manure N. It can be lost to the atmosphere, exported by fresh runoff into the holding pond or remains in scraped manure.

Nutrient concentrations for manure and effluent irrigation needed to be entered into the survey. From this data and the predicted volume of runoff, N levels in manure and the holding pond were estimated. From mass balance, the remaining N is lost to the atmosphere as volatilisation.

In 2002, approximately 92% of the N in manure is lost to the atmosphere from volatilisation with the remaining lost in fresh runoff (2%) and scraped manure (6%). This compares with 92% of the manure N volatilised, 4% lost in runoff and 4% remaining in scraped manure in 2004.

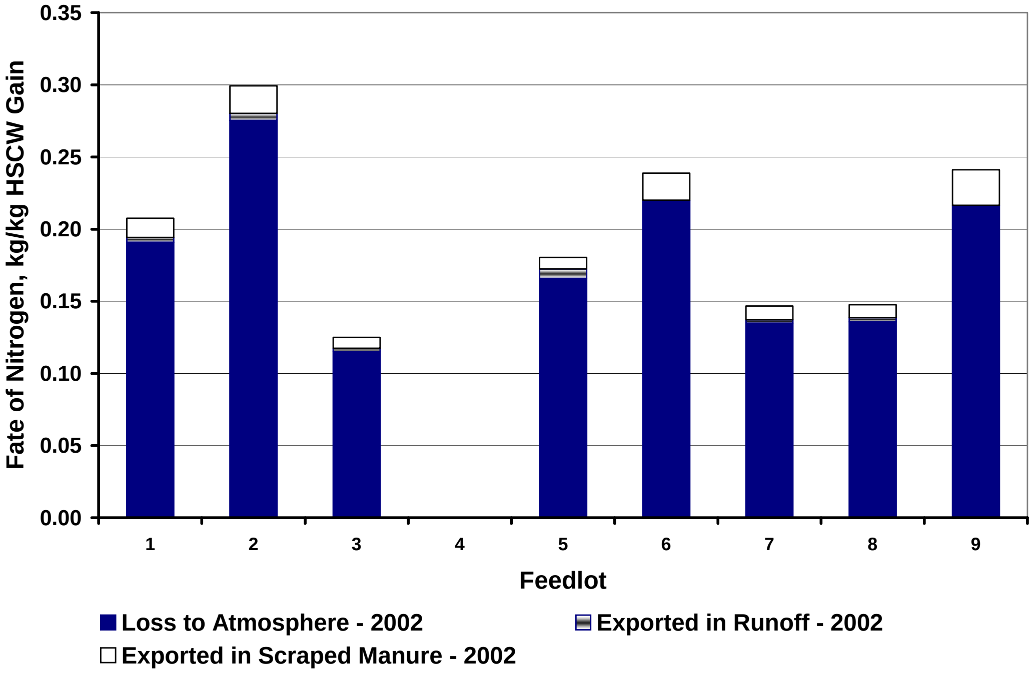

FIGURE 13 – FATE OF MANURE N - 2002

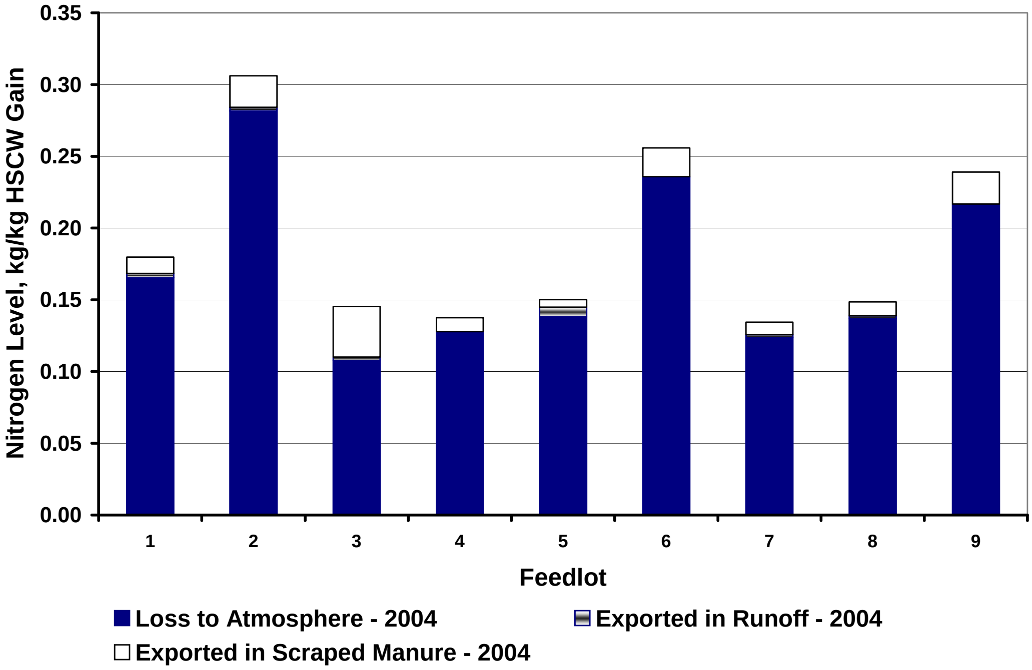

FIGURE 14 – FATE OF MANURE N - 2004

6.2.4 P Inputs

Figure 15 and Figure 16 present results for P input levels from the nine surveyed feedlots for the 2002 and 2004 survey years respectively. The input contribution from P in water represented less than 30 mg/kg HSCW gain of the total P input, a very minor contribution when compared with incoming cattle and feed levels.

Total P input ranges from 0.051-0.064 kg/kg HSCW gain for the nine surveyed feedlots during the 2002 survey year. This level is around one fifth of the total N input level. The P content incoming cattle ranges from 0.012-0.029 kg/kg HSCW gain, with feed intake level ranging from 0.028-0.052 kg/kg HSCW gain. The contribution of P from feed ranges from 47 to 80% of the total P input.

For 2004, total P input ranges from 0.048-0.070 kg/kg HSCW gain for the nine surveyed feedlots and are similar to 2002 input levels. The P input from incoming cattle ranged from 0.016-0.029 kg/kg HSCW gain, with feed intake contributing 0.028-0.054 kg/kg HSCW gain. The contribution of P from feed ranges from 56-77% of the total P input.

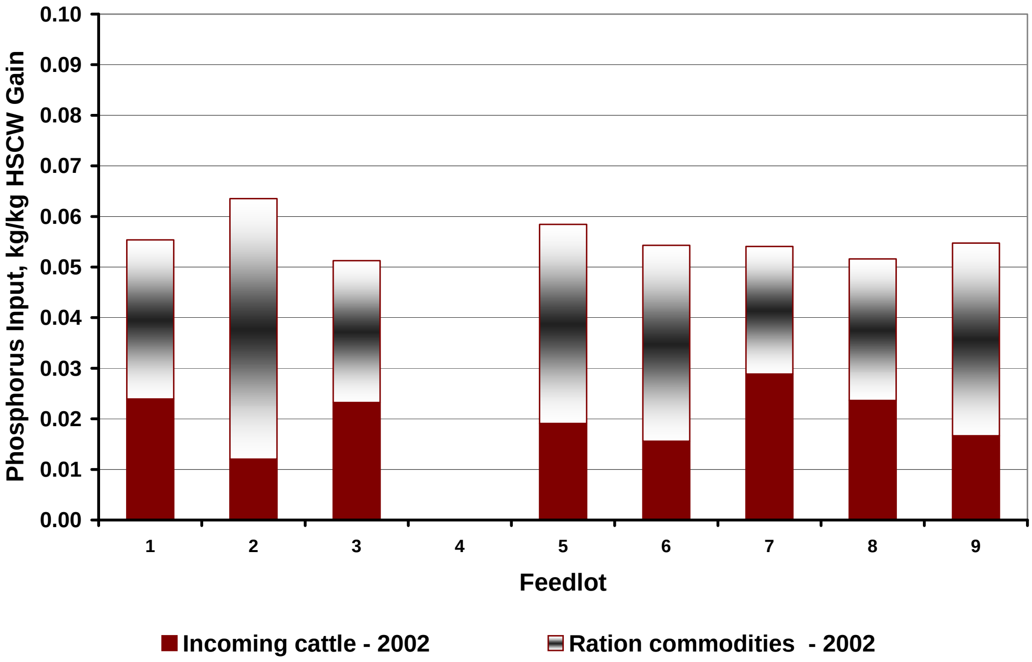

FIGURE 15 – INCOMING P LEVELS IN CATTLE AND FEED FOR 2002 SURVEY YEAR

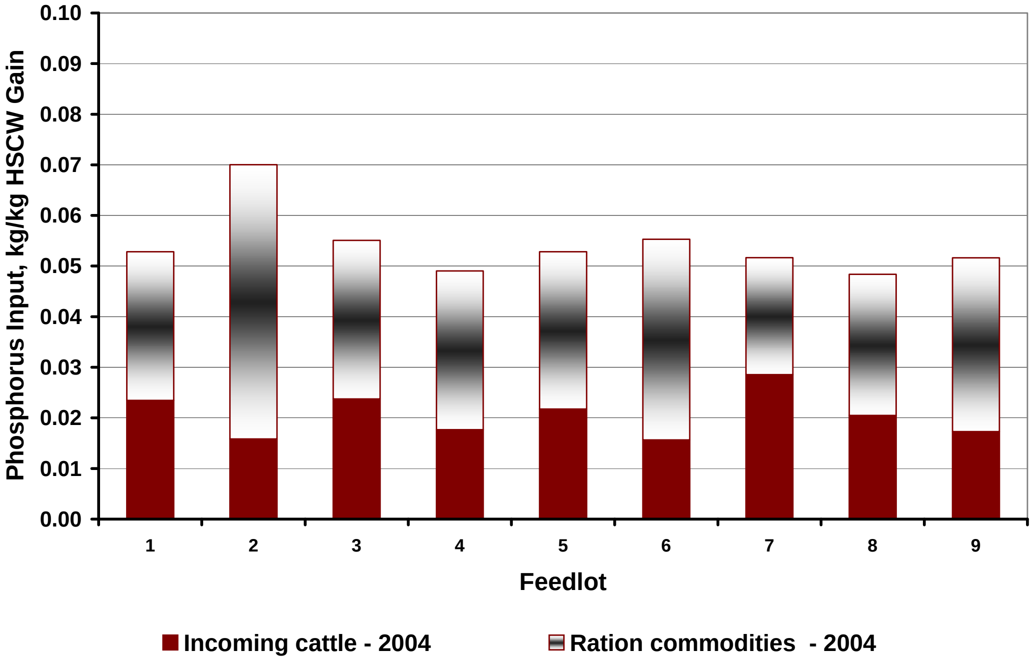

FIGURE 16 – INCOMING P LEVELS IN CATTLE AND FEED FOR 2004 SURVEY YEAR

Total P input levels per kg HSCW gain are similar across most feedlots with the exception of Feedlot 2 which has a marginally greater input. A greater variation was found between P levels in incoming feed and this variation can be attributed to the various commodities.

6.2.5 P Outputs

Figure 17 and Figure 18 present results on P output levels from the nine surveyed feedlots for the 2002 and 2004 survey years respectively. The P leaving the system in mortalities represented less than 400 mg/kg HSCW gain of the total P output, a very minor contribution when compared with outgoing cattle and manure.

Total P output ranges from 0.051-0.063 kg/kg HSCW gain for the nine surveyed feedlots during the 2002 survey year. P output for outgoing cattle varies between 0.023 kg/kg HSCW gain (Feedlot 2) to 0.038 kg/kg HSCW gain (Feedlot 7) and P levels in manure ranges from 0.017 kg/kg HSCW gain (Feedlot 3) to 0.039 kg/kg HSCW gain (Feedlot 2). For the 2004 survey year total P output levels ranged from 0.048-0.068 kg/kg HSCW gain for the nine surveyed feedlots and are similar to 2002 output levels.

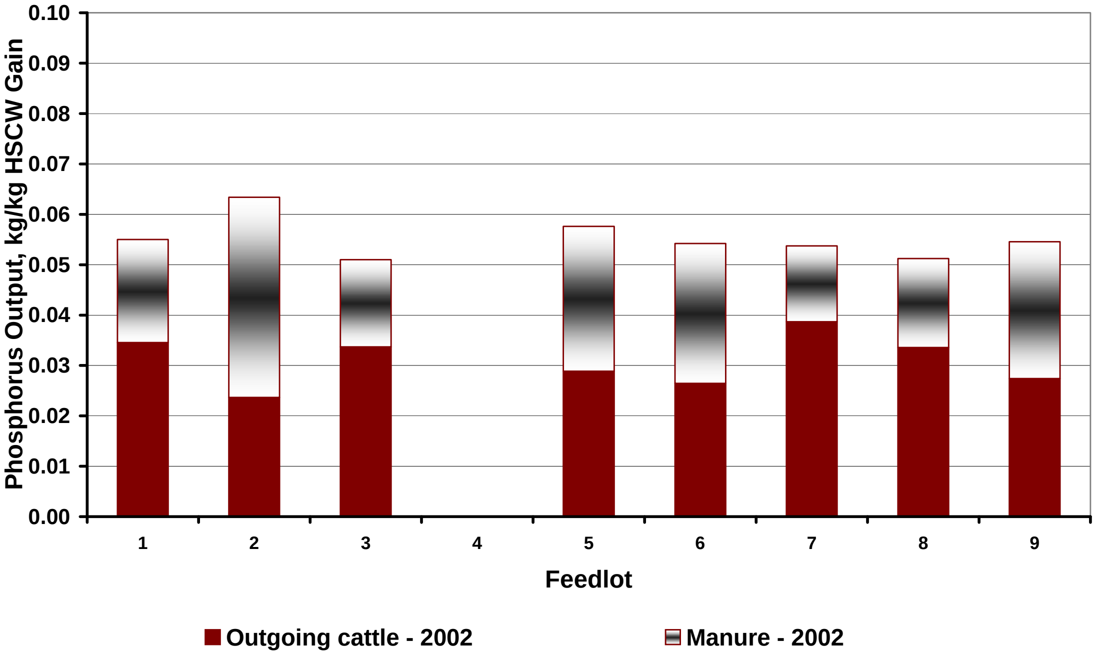

FIGURE 17 – OUTGOING P LEVELS IN CATTLE AND MANURE FOR 2002 SURVEY YEAR.

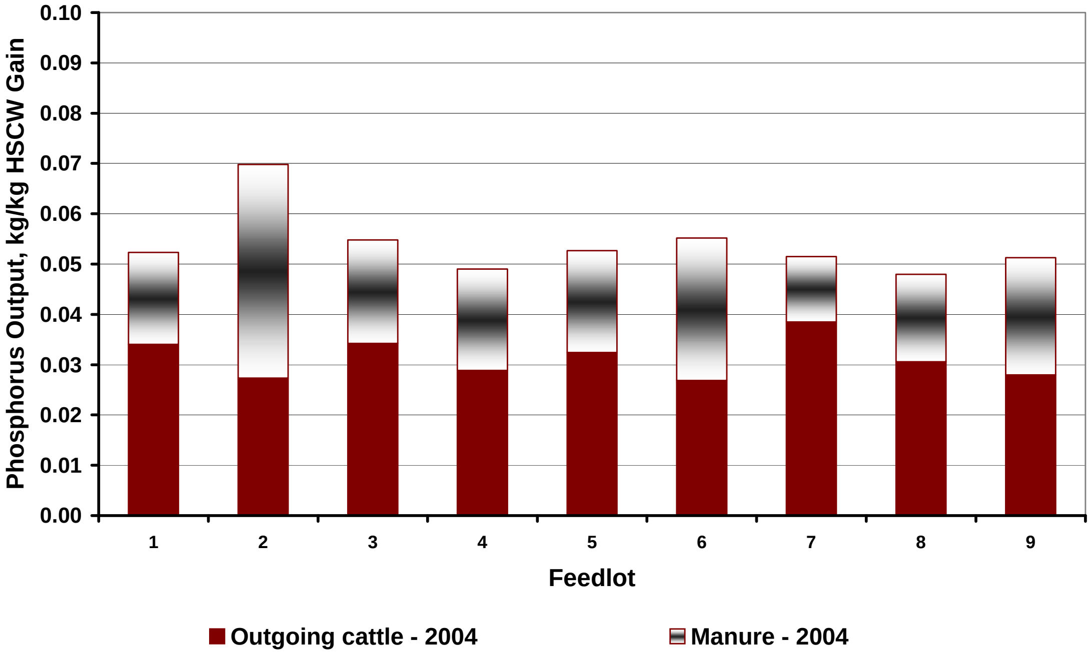

FIGURE 18 – OUTGOING P LEVELS IN CATTLE AND MANURE FOR 2004 SURVEY YEAR.

Total P output levels per kg HSCW gain are similar across most feedlots with the exception of Feedlot 2, which has a marginally greater output. This corresponds with the higher input in Feedlot 2. Diet type resulting from differences in commodity usage between market types is the most likely reason of the level of P in manure, with the feedlots with long-fed cattle (Feedlots 2, 6 & 9) having a higher P level in manure.

6.2.6 Fate of Manure P

Figure 19 and Figure 20 illustrate the pathways for P contained in manure from the nine surveyed feedlots for the 2002 and 2004 calendar years respectively. Two possible pathways exist for manure P, exported in fresh runoff to the holding pond or remaining in scraped manure. No P is lost to the atmosphere.

Most P is retained in scraped manure which contains some 94-99% of the total P contained in the manure. The remaining P is exported during runoff into the holding pond.

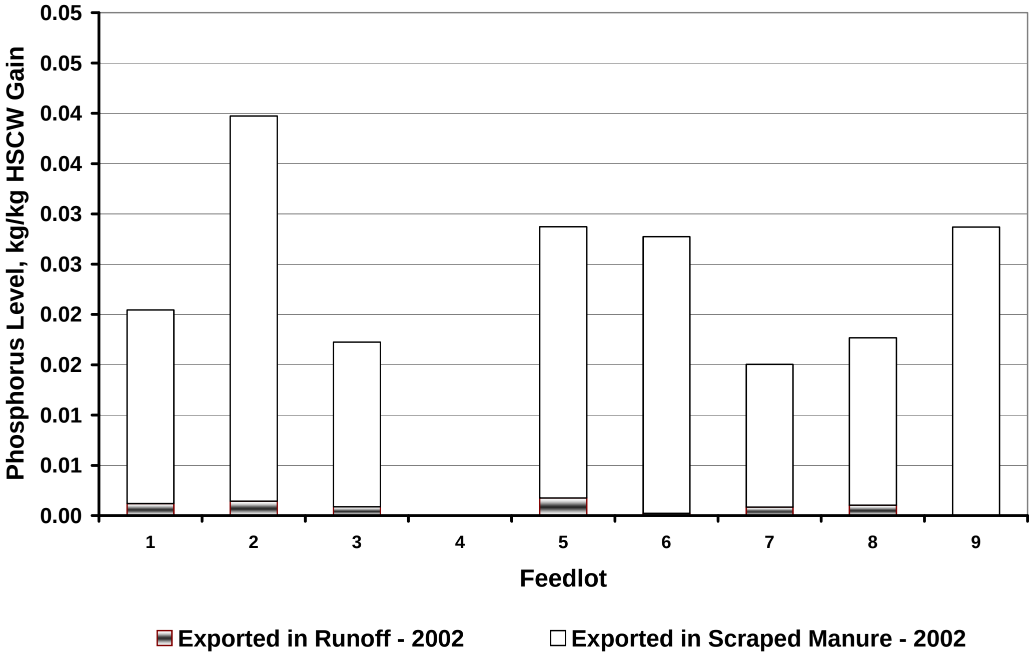

FIGURE 19 – FATE OF MANURE P - 2002

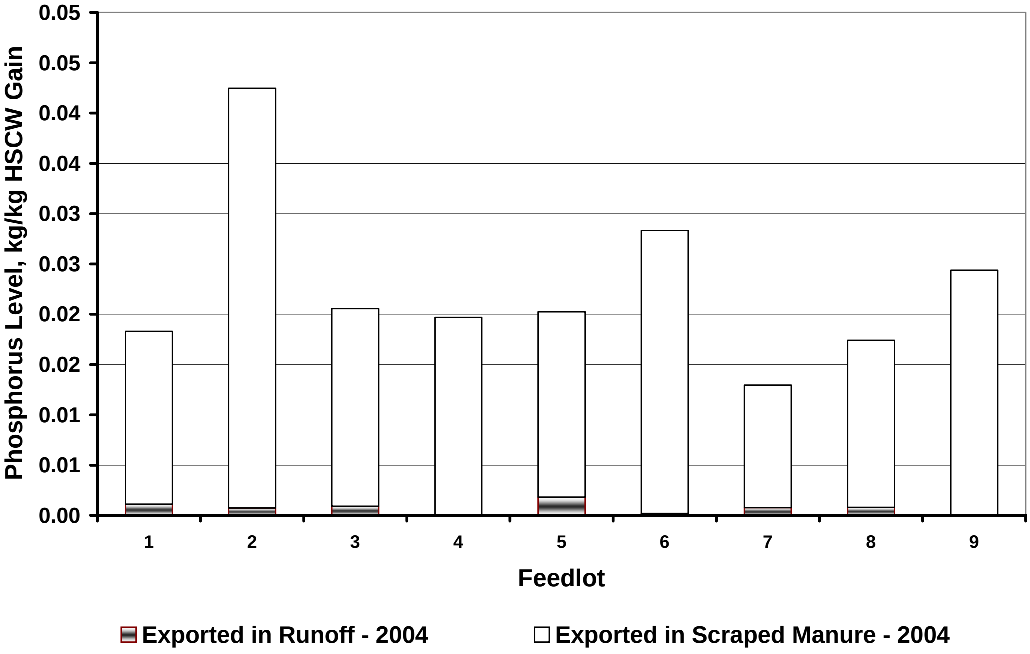

FIGURE 20 – FATE OF MANURE P - 2004

6.2.7 K Inputs

Figure 21 & Figure 22 illustrate the K input levels from the nine surveyed feedlots for the 2002 and 2004 survey years respectively. The input contribution from K in water represented less than 30 mg/kg HSCW gain of the total K input, a very minor contribution when compared with incoming cattle and feed levels.

Total K input ranged from 0.05-0.13 kg/kg HSCW gain for the nine surveyed feedlots during the 2002 survey year. This level is around one fifth of the total N input level and similar to P input levels. The component for incoming cattle ranges is typically less than 0.01 kg/kg HSCW gain, with feed intake levels ranging from 0.05-0.13 kg/kg HSCW gain. The contribution of K from feed ranges is typically greater than 90% of the total K input. For 2004, total K input levels ranged from 0.06-0.1 kg/kg HSCW gain for the nine surveyed feedlots and were slightly less than 2002 levels.

The quantity of K required to produce a kilogram of HSCW gain for Feedlot 2 is twice that required for Feedlots 1, 3 & 8 in 2002. K input levels per kg HSCW gain for incoming cattle are similar across all feedlots in 2002 and 2004. Hence, the variation in K input levels is from the incoming feed.

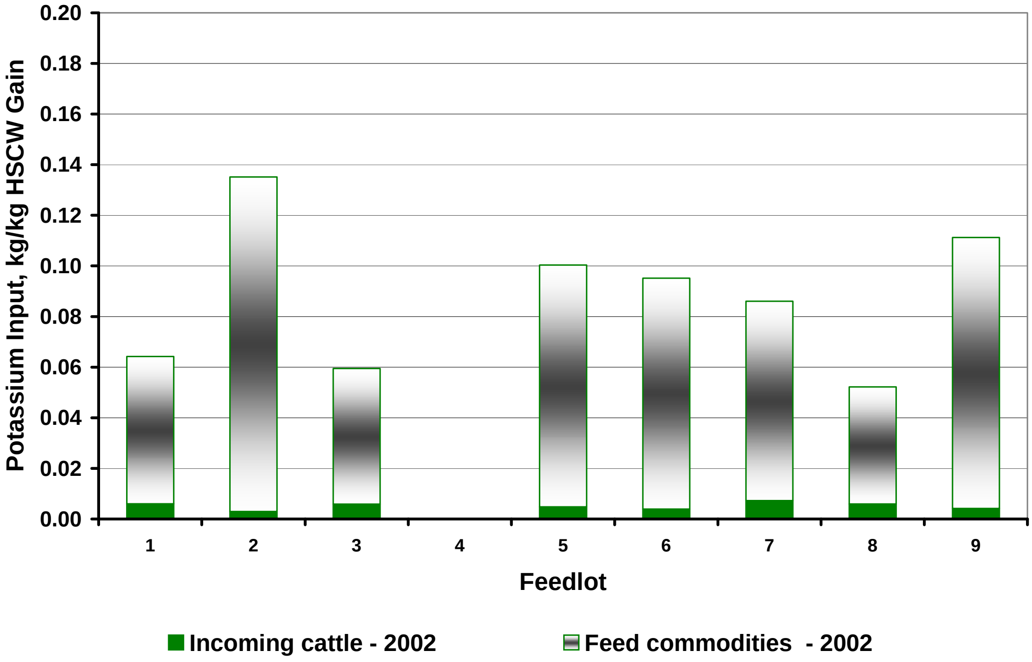

FIGURE 21 – INGOING K LEVELS IN CATTLE AND MANURE FOR 2002 SURVEY YEAR

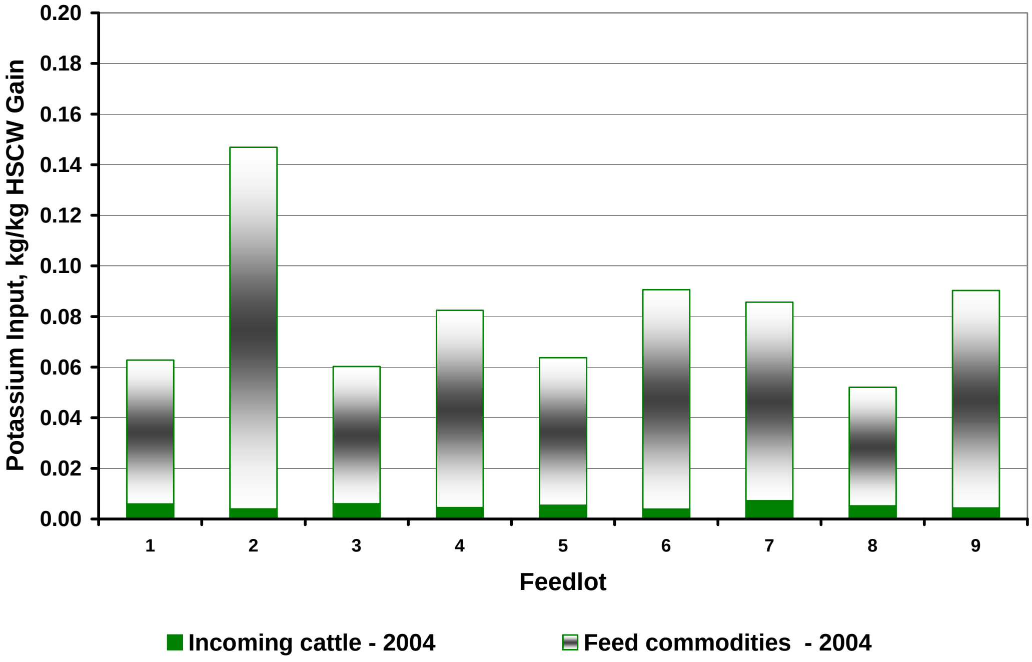

FIGURE 22 – INCOMING K LEVELS IN CATTLE AND MANURE FOR 2004 SURVEY YEAR

6.2.8 K Outputs

Figure 23 & Figure 24 illustrate the total K output levels from the nine surveyed feedlots for the 2002 and 2004 survey years respectively. .

Total K output ranges from 0.052-0.135 kg/kg HSCW gain for the nine surveyed feedlots during the 2002 survey year. K output is partitioned between outgoing cattle (0.01 kg/kg HSCW gain) and manure (0.06-0.09 kg/kg HSCW gain). The K leaving the system in mortalities represented less than 90 mg/kg HSCW gain of the total K output, a very minor contribution when compared with outgoing cattle and manure. Similar, total K output levels were found for the 2004 survey year and ranged from 0.052-0.147 kg/kg HSCW gain for the nine surveyed feedlots (Figure 24).

A significant variation exists between total K output levels per kg HSCW gain across all feedlots. This variation is from the variations in the dietary K levels that result from the range of ingredients used in rations. Feedlot 2 feeds a high proportion of molasses (up to 9%), in their ration which has a high K concentration.

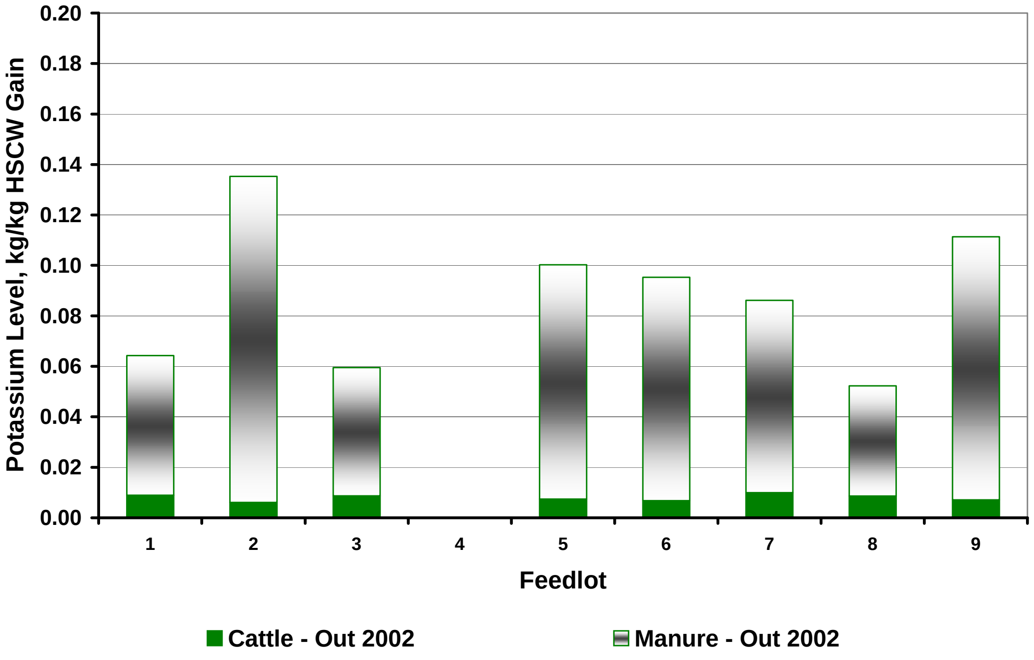

FIGURE 23 – OUTGOING K LEVELS IN CATTLE AND MANURE FOR 2002 SURVEY YEAR

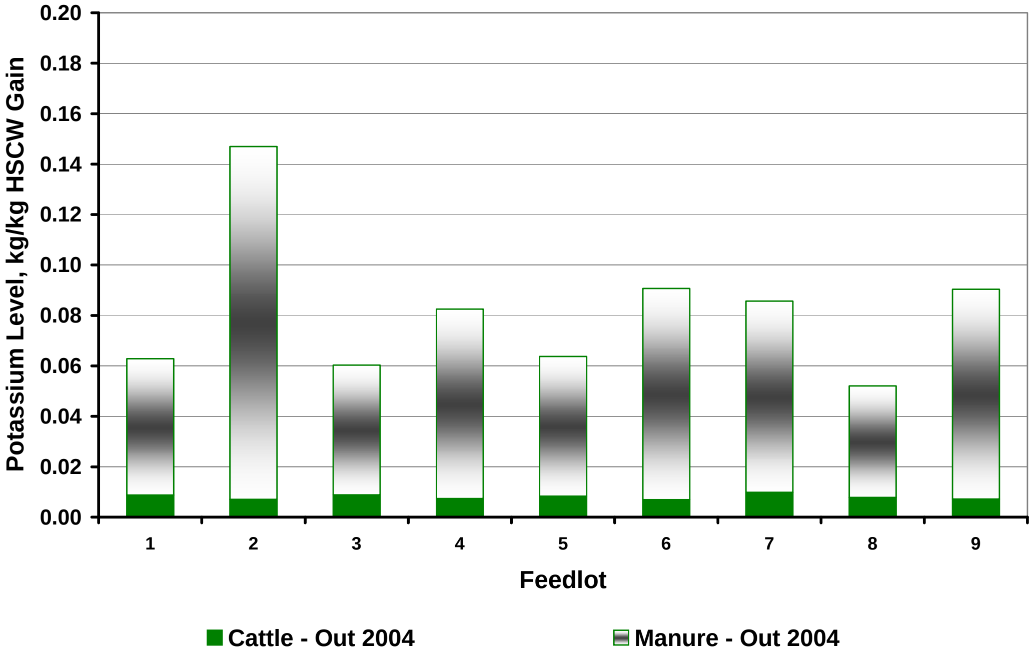

Figure 24 – Outgoing K Levels in Cattle and Manure for 2004 survey year

6.2.9 Fate of Manure K

Figure 25 & Figure 26 illustrate the fate of manure K from the nine surveyed feedlots for the 2002 and 2004 calendar years respectively. Two possible pathways exist for manure K, either exported by runoff into the holding pond or remain in scraped manure.

During the 2002 calendar year, the percentage of K retained in scraped manure ranged from 65% to 99%. The remaining K was exported during runoff into the holding pond. No K was lost to the atmosphere. This compares with 2004, where the percentage of K retained in scraped manure ranged from 35% to 96%.

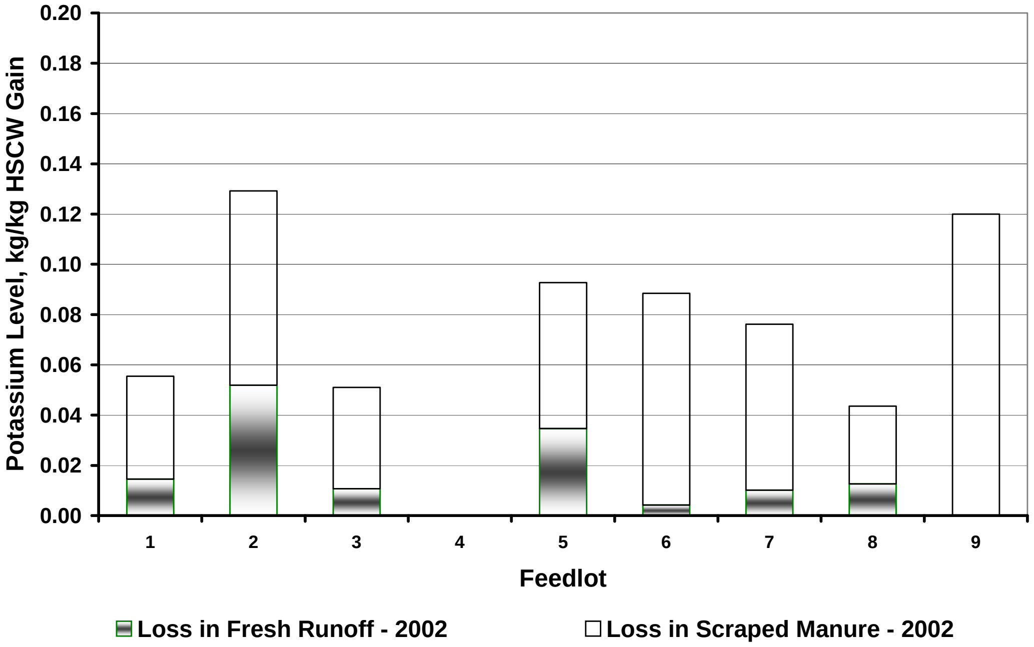

FIGURE 25 – FATE OF MANURE K - 2002

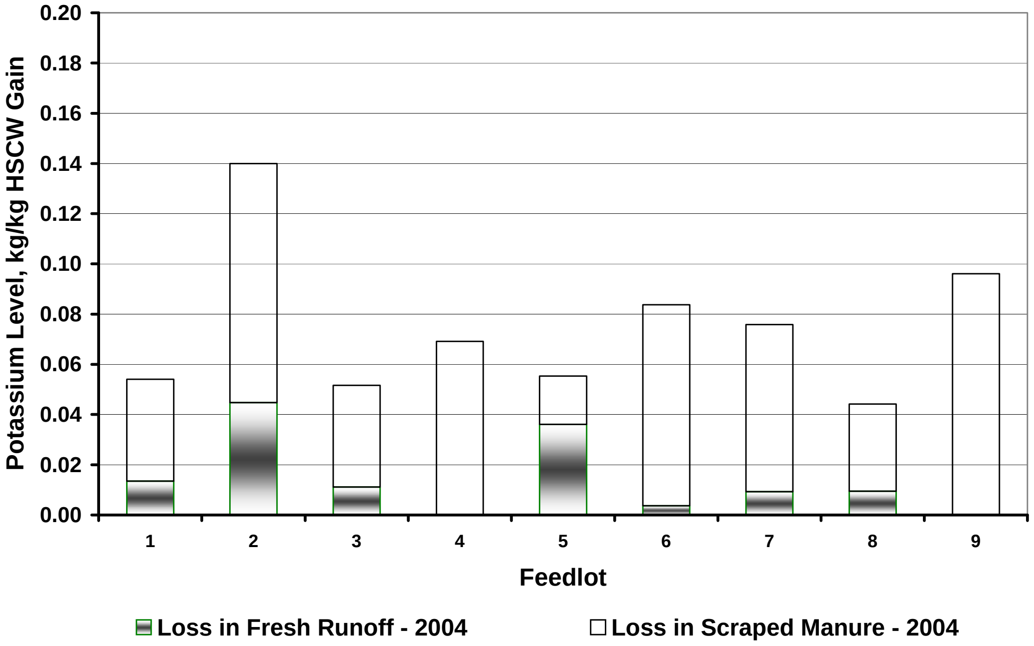

FIGURE 26 – FATE OF MANURE K - 2004

7 Conclusions and Recommendations

7.1 Conclusions

Nutrient pathways into and out of feedlots are complex and diverse. Nutrients enter the feedlot in cattle, feed and water and leave the feedlot in cattle, scraped manure, effluent, atmospheric losses and water flows. Inputs and feedlot management govern the concentration of N, P and K contained in each of these outputs. For example, the weight of cattle on exit, the timeframe over which they are fed, the diet they consume and the manure and effluent treatment system all have an influence.

Extensive research has been undertaken in the areas of animal nutrition, growth and composition. Over the past decade, there has been a significant development of the feedlot industry in terms of feeding for specific market and manure management.

The literature contains a wide range of reported rates of nutrient excretion by feedlot cattle. However, information on N losses through NH_3 volatilisation is patchy.

Research involving nine Australian feedlots showed that total N input ranges from 0.24-0.38 kg/kg HSCW gain. The contribution of N from diet ingredients was found to range from 60-87% of the total N input. Some 50–80 % of the incoming N ends up in the manure. Over 90 % of the manure N is lost to the atmosphere from volatilisation, with the balance exported in runoff and scraped manure.

Total P input level was found to be around one fifth of the total N input. The contribution of P from feed ranges from 47-80% of the total P input. Total P output ranges from 0.051-0.063 kg/kg HSCW gain with 0.017-0.039 kg/kg HSCW gain of this in the manure. Variations in diet composition are the most likely reason of the level of P in manure, with the feedlots with long-fed cattle producing manure with a higher P level in manure. Of the P deposited to manure, some 94-99% remains in the manure on the pad with the balance exported to the effluent ponds in rainfall runoff.

Total K input is 0.05-0.13 kg/kg HSCW gain, which is similar to the P input level. Over 90% of the K is from feed. K output is partitioned between outgoing cattle (0.01 kg/kg HSCW gain) and manure (0.06-0.09 kg/kg HSCW gain). The percentage of K retained in scraped manure ranges from 65% to 99%. The remaining K is exported during runoff into the holding pond.

The outcomes of this study will allow the feedlot industry to develop a better understanding of the relativity and pathways for nutrient cycling and provide factual information on the life cycle inventory for major nutrients. Knowledge of the total nutrient input and output levels will allow the industry to benchmark itself against other intensive or extensive livestock industries and or industrial processes.

7.2 Recommendations

More research into ammonia ($NH_{3)}$ and nitrous oxide (N_20) losses from Australian feedlot pads, manure stockpiles and compost heaps, holding ponds, manure spreading and effluent irrigation is recommended. This would enhance knowledge about the magnitude of these losses to the atmosphere and provide better information for managing reuse of manure and effluent. In addition, knowledge of N_20 losses would allow improvement in the estimation of GHG emissions.

Further research into methods for minimising NH_3 and N_20 losses from feedlot systems is also recommended. This would enable N to be retained in manure and effluent where it is a valuable plant nutrient. It would also enable the minimisation of NH_3 emissions to the atmosphere.

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Environmental Sustainability Assessment of the Australian Feedlot Industry

Part D Report: NPI Listed Substances Emission Estimation

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Abstract

The Australian red meat industry, as with most primary industries, is coming under increasing pressure from both the community and government to document and justify its impacts on the environment. Australian industries are required to report to the National Pollutant Inventory (NPI) the types and amounts of certain substances used in production. Australian feedlots have reporting obligations if their use of these substances exceeds specified thresholds.

Ammonia (NH_3) is an NPI Category 1 listed substance. Beef cattle feedlots “use” NH_3 through the co-production of NH_3 as a by-product of manure. Feedlot operators are required to report their NH_3 emissions to the NPI if it is estimated that their use of NH_3 exceeds 10 t/yr. Larger feedlots may also trigger reporting for energy consumed or fuel used.

This study provides a summary of the NPI reporting framework and quantifies nitrogen excretion levels in fresh manure using site-specific data. A comparison between nitrogen excretion levels from site-specific data and NPI default values was undertaken.

Executive Summary

The Australian red meat industry, as with most primary industries, is coming under increasing pressure from both the community and government to document and justify its impacts on the environment. Currently, a lack of credible supply chain data prevents the industry from being able to respond in a meaningful manner.

Meat and Livestock Australia (MLA) is undertaking a project (COMP.094) that will address these issues and provide credible data on the industry's environmental impacts and sustainability for use by industry, including its interactions with government, community groups and the media. This undertaking will utilise the standardised tool, Life Cycle Analysis (LCA), to quantify natural resource consumption and environmental interventions to water, soil and air.

LCA is a form of cradle-to-grave system analysis developed for use in manufacturing and processing industries to assess the environmental impacts of products, processes and activities by quantifying their environmental effects throughout the entire life cycle. An LCA is essentially a quantitative study. Sometimes environmental impacts cannot be quantified due to a lack of data or inadequate impact assessment models. Quantitative analysis requires standardised databases of main processes (e.g. energy, transport) and software for managing the study's complexity.

As part of the overall industry project, the beef cattle lotfeeding sector is undertaking a related project that will contribute to the whole of industry dataset, but more importantly addresses the public misconceptions of the environmental sustainability of the feedlot industry. It will identify and quantify the environmental costs associated with the production of one kilogram of grained beef compared to its domestic competing products (grass fed beef, lamb, pig and poultry meats).

MLA funded a project (FLOT .328) to measure environmental costs associated with the production of one kilogram of meat from modern Australian feedlots. The data is to be used to benchmark the environmental sustainability of the feedlot industry against its domestic and international competitors.

Australian industries are required to report to the National Pollutant Inventory (NPI) the types and amounts of certain substances used in production. Australian feedlots have reporting obligations if their use of these substances exceeds specified thresholds. Hence, it could be assumed that the NPI could provide data for use in LCA for feedlots.

Each year, Australian intensive livestock facilities must estimate their use of National Pollutant Inventory (NPI) listed substances and report their emissions directly to their state or territory environment agency if they exceed specified thresholds. Currently, the NPI has five different threshold categories that separate the 90 listed substances into those resulting from production and combustion or other thermal processes. Thresholds are based on compound use rather than emissions. Thresholds are separated into Category 1, Category, 1a, Category 2, Category 2a and Category 3. Each of the NPI listed substances has at least one threshold against it. It is necessary to report emissions for all substances where the threshold/s for that substance is exceeded.

Beef cattle feedlots "use" ammonia (NH_3) through the co-production of NH_3 as a by-product of manure. Feedlot operators are required to report their NH_3 emissions to the NPI if it is estimated that these exceed 10 t/yr. Larger feedlots may trigger NPI reporting requirements for Category 2 –

substances from combustion as a result of energy or fuel usage. An unplanned release of effluent to surface waters could trigger Category 3 reporting requirements.

This report covers the issue of nitrogen (N) excretion levels by the feedlot production system and contains a summary of the NPI reporting framework.

As part of the FLOT.328 project, factual information was obtained via a detailed on-line survey of feedlot inputs and outputs including cattle numbers, intake and sale weights, dressing percentages and diet. The results show that modern Australian feedlots use a wide range of management systems including a variety of diet formulations, feed processing systems, market types, feed delivery and waste treatment systems. Annual N excretion levels and ammonia (NH_3) emissions were estimated in terms of dressed carcass weight gain (kg HSCW gain). In this context, HSCW gain is the difference between total dressed carcass weight of cattle leaving the feedlot less the estimated total dressed carcass weight of cattle entering the feedlot.

Around 75% of Australian feedlots should be reporting at least Category 1 emissions of NH_3 to air. However, the NPI database indicates that only 14% of facilities are reporting NH_3 emissions. Hence, due to the low level of reporting compliance, it is not recommended that NPI data be used in feedlot LCA studies.

From the survey, the estimated N excretion per standard cattle unit (SCU) per year for freshly excreted manure ranged from 52 kg to 105 kg with a median value of 68 kg for the nine feedlots included. N excretion rates depended upon the composition of processed diets, which are complex in formulation and vary depending upon the availability and cost of various ingredients.

The NPI standard estimate of 75 kg N/SCU/yr probably overestimates the probable manure N excretion by about 10% based on the results of mass balance modelling using the survey data. Partly, this is because the NPI standard relies on an estimate of manure production based on animal mass rather than feed intake. As well, the use of a single generic N excretion factor for feedlot cattle ignores the wide range in N excretion reported for feedlot cattle.

The NPI default values for N volatilisation assume that 90% of the total N excreted is volatilised. From data collected in the survey, total N emissions to the atmosphere were estimated to average 88%. The NPI default values and the values calculated from the survey results were similar.

Overall, our findings suggest that the use of default data for calculating NH_3 emissions in lieu of site-specific data means that the industry as a whole is probably overestimating these emissions by 10%.

There are three main sources that might contribute to the overestimation of NH_3 emissions from feedlots. These include using licensed capacity or pen capacity as the default herd capacity, using the default NPI N excretion value and using default NPI volatilisation rates for individual manure management components.

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1 Background

The Australian red meat industry, like most primary industries, is coming under increasing pressure from both the community and government to document and justify its impacts on the environment. This is evident through the government emphasis on industry initiatives, such as the implementation of Environmental Management Systems (EMS), and Triple Bottom Line (TBL) reporting requirements. Currently, a lack of credible supply chain data prevents the industry from being able to respond in a meaningful manner.

Meat and Livestock Australia (MLA) is undertaking a project (COMP.094) that will address these issues and provide credible data on the industry's environmental impacts and sustainability for use by industry, including its interactions with government, community groups and the media. This project will utilise the standardised tool, Life Cycle Analysis (LCA), to quantify natural resource consumption and environmental interventions to water, soil and air.

A separate but related project (FLOT.328) is being undertaken for the lot-feeding sector of the Australian red meat industry.

1.1 FLOT.328 Project Description

As part of the overall industry project, the beef cattle lotfeeding sector is undertaking a related project (FLOT.328) that will contribute to the whole of industry dataset, but more importantly addresses the public misconceptions of the environmental sustainability of the feedlot industry. It will identify and quantify the environmental costs associated with the production of one kilogram of grained beef to enable comparison with its domestic competing products (grass fed beef, lamb, pig and poultry meats).

Given that environmental sustainability will eventually become a key element in maintaining and improving access for Australian product into key overseas markets, it is envisaged that project FLOT.328 will also benchmark these costs against international competitors (US and European beef) and identify areas of R&D investment to ensure the long-term viability and sustainability of the feedlot production system. Australian industries are required to report to the National Pollutant Inventory (NPI) the types and amounts of certain substances used in production. Australian feedlots have reporting obligations if their use of these substances exceeds specified thresholds. Hence, NPI data could be used as an indication of environmental performance of Australian feedlots. This study of National Pollutant Inventory (NPI) emissions from Australian feedlots is part of FLOT.328.

2 Project Objectives

The FLOT.328 project will:

1. Collect, collate and present relevant data to enable MLA to assess/benchmark the environmental sustainability of the feedlot industry against its domestic and international competitors by assessing the environmental costs associated with the production of one kilogram of meat from each production system
2. Provide data for the feedlot industry suitable for use within the broader red meat supply chain LCA (COMP.094).
3. Identify areas for potential future R&D investment to ensure long-term competitiveness, viability and sustainability of the feedlot production system.
4. Communicate the results of the assessment to MLA in a format suitable for dissemination to industry stakeholders.

This report covers the issue of emissions of NPI-listed substances by feedlots (see Section 4.1). The NPI emission estimation manual for Intensive Livestock - Beef Cattle (feedlot EET manual) was developed to assist intensive beef cattle producers in estimating and reporting emissions. The manual provides a comprehensive description of procedures and recommended approaches for estimating emissions. This report aims to provide a summary of the NPI reporting requirements and to provide updated information on the quantity of emissions required to produce red meat within the feedlot sector only.

2.1 Project Reporting Structure

This project includes the collection and analysis of a large quantity of data from operational feedlots on the environmental costs associated with the production of one kilogram of hot standard carcass weight (HSCW). In this context, HSCW gain is the difference between total dressed carcass weight of cattle leaving the feedlot less the estimated total dressed carcass weight of cattle entering the feedlot. To ensure all this data and information is presented in a suitable manner, six reports have been compiled.

A. Water Usage at Australian Feedlots. This report presents a background literature review of water usage at feedlots, data collection and results, as well as an analysis and discussion of the data collected. This report is the life cycle inventory for the water use component of the feedlot sub-system.

B. Energy Usage and Greenhouse Gas Emission Estimation at Australian Feedlots. This report presents a background literature review of energy usage and GHG emissions at feedlots, data collection and results. A discussion of results and the relative merits of the current GHG emission calculation methodology by the Australian Greenhouse Office (AGO) are included. This report is the life cycle inventory for the energy use and GHG emissions component of the feedlot sub-system.

C. Nutrient Cycling at Australian Feedlots. This report includes a literature review of nutrient pathways at feedlots, data collection and results as well as an analysis and discussion of the data collected. This report is the life cycle inventory for the nutrient cycling component of the feedlot sub-system.

D. NPI Listed Substances Emission Estimation for Australian Feedlots. This report provides a summary of the NPI reporting framework, data collection and results for category I listed substances. The report also includes a discussion of the relative merits of the current NPI emission estimation methodology, with guidance on an alternative method for use under Australian conditions.

E. Review of Lot Fed Cattle Water Consumption – MRC Project No. DAQ.079. This report provides a review of research undertaken in the early 1990's on water consumption in feedlots. It provides a more detailed literature review on the factors influencing drinking water requirements than is provided in Part A, experimental methodology, data collected and discussion of the results and outcomes of this MRC research.
F. Resource Use and Environmental Impact Assessment for Australian Feedlots. This report provides a summary of feedlot-relevant natural resources management (NRM) issues, data collection and results. A discussion of the environmental impact of the use of these resources by beef cattle feedlots is also included.

3 Life Cycle Assessment

MLA is undertaking a project (COMP.094) that will provide credible data on the red meat industry's environmental impacts and sustainability for use by industry, including its interactions with government, community groups and the media. This project will utilise the standardised tool, LCA, to quantify natural resource consumption and environmental interventions to water, soil and air. This project (FLOT.328) is being undertaken for the lot-feeding sector of the Australian red meat industry. The following description of LCA is taken from Peters et al. (2005).

3.1 Description of Life Cycle Assessment

LCA is a form of cradle-to-grave systems analysis developed for use in manufacturing and processing industries to assess the environmental impacts of products, processes and activities by quantifying their environmental effects throughout the entire life cycle. LCA can be used to compare alternative products, processes or services; to compare alternative life cycles for a product or service; and to identify those parts of the life cycle where the greatest improvements can be made. An international standard has now been developed to specify the general framework, principles and requirements for conducting and reporting LCA studies (Standards Australia 1998). LCA differs from other environmental tools (e.g. risk assessment, environmental performance evaluation, environmental auditing and environmental impact assessment) in a number of significant ways. In LCA, the environmental impact of a product or the function a product is designed to perform is assessed, the data obtained are independent of any ideology and it is much more complex than other environmental tools. As a system analysis, it surpasses the purely local effects of a decision and indicates the overall effects.

There are four aspects of life cycle assessment (see Figure 1):

- *Goal and Scope Definition* defines the goal, functional unit and associated system to be studied.
- *Inventory Analysis* analyses all process inputs and outputs. It involves modelling unit processes in the system, considered as inputs from the environment (resources and energy) and outputs (product, emissions and waste) to the environment. Allocation of inputs and outputs needs to be clarified where processes have several functions (for example, where one production plant produces several products). In this case, different process inputs and outputs are attributed to the different goods and services produced. An extra simplification used by LCA is that processes are generally described without regard to their specific location and time of operation.
- *Impact Assessment* makes results from the inventory analysis more manageable and understandable in relation to natural environment, human health and resource availability.
- *Interpretation* involves evaluating inventory analysis and impact assessment outcomes against the study's goal.

An LCA is essentially a quantitative study. Sometimes environmental impacts cannot be quantified due to a lack of data or inadequate impact assessment models. Quantitative analysis requires standardised databases of main processes (energy, transport) and software for managing the study's complexity.

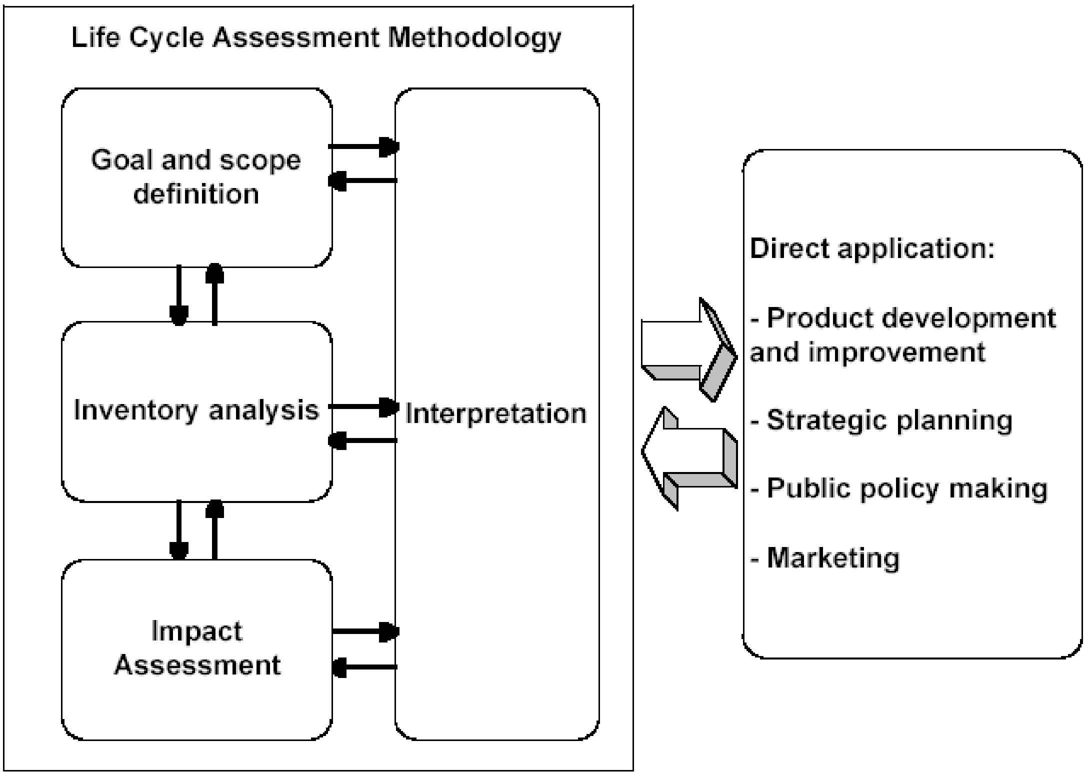

Figure 1 – General Framework for LCA and its Application (Standards Australia 1998)

3.2 Selection of Functional Unit

The functional unit for this study is the delivery of one kilogram of hot standard carcass weight (HSCW) meat at the abattoir. AUS-MEAT is the authority for uniform specifications for meat and livestock in Australia. In March 1987, they introduced the term HSCW as a national standard. The HSCW is the fundamental unit of “over the hooks” selling and is the weight, within two hours of slaughter, of a carcass with standard trim (all fats out). This is a carcass after bleeding, skinning, removal of all internal organs, minimum trimming and removal of head, feet, tail and other items (AUS-MEAT, 2001). “Hot” indicates that the meat in question has not entered any chilling operations. This output-related functional unit was chosen, rather than an input-related one, in order to describe the human utility of the processes under consideration – the provision of nutrition for people. Although the meat could be served in different ways, this functional unit makes the different processes under consideration “functionally equivalent” from a dietary perspective.

3.3 System Boundaries

In LCA methodology, usually all inputs and outputs from the system are based on the 'cradle-to-grave' approach. This means that inputs into the system should be flows from the environment, without any transformation from humans. Outputs should also be discarded to the environment without subsequent human transformation (Standards Australia 1998). Each system considers upstream processes with regard to the extraction of raw materials and the manufacturing of products being used in the system and it considers downstream processes as well as all final emissions to the environment.

Figure 2 shows the generalised system boundary for the red-meat sector as defined for the COMP.094 project. Within this boundary, there is a sub-system for the feedlot sector. The boundary chosen here (shown in red on Figure 2) is the feedlot site itself, plus the transport component of bringing cattle and feed into the feedlot and delivering cattle from the feedlot. The production of feed for the feedlot will be examined in a larger system analysis.

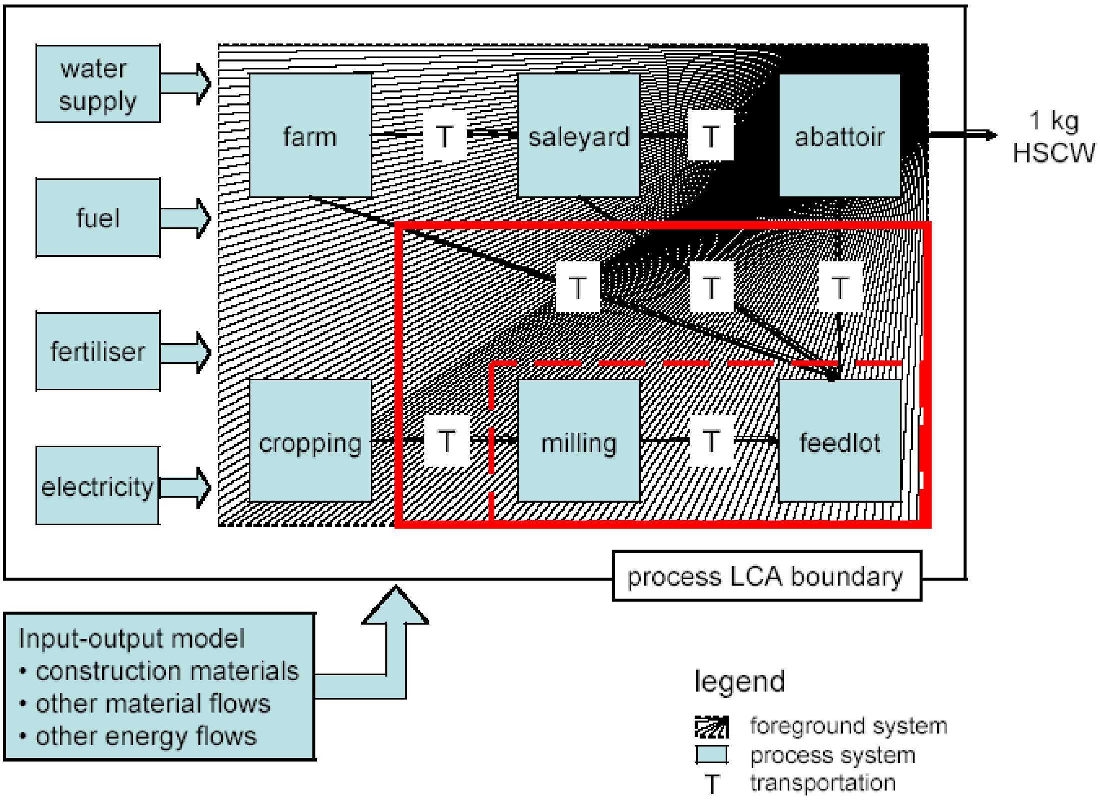

Figure 2 – Generalised System Model for the Red Meat Sector with Feedlot Sub-system

3.4 Life Cycle Inventory

Inventory analysis is the second phase in a life cycle assessment and is concerned with data collection and calculation procedures. The Inventory Analysis phase forms the body of the LCA, as the majority of time and effort in an LCA is spent on Inventory Analysis. As a rule of thumb, 80% of the time required for an LCA is needed for this phase. The operational steps in preparing a life cycle inventory (LCI) are according to ISO 14041 (Standards Australia 1999):

- Data collection.
- Relating data to unit processes and/or functional unit.
- Data aggregation.
- Refining the system boundaries.

Australian industries are required to report to the National Pollutant Inventory (NPI) the types and amounts of certain substances used in production. Australian feedlots have reporting obligations if their use of these substances exceeds specified thresholds. Hence, it could be assumed that the NPI could provide data for use in the Life Cycle Assessment of feedlots. This report covers the issue of nitrogen (N) excretion levels by the feedlot production system and contains a summary of the NPI reporting framework.

4 Literature Review

4.1 National Pollution Inventory

The National Environment Protection Council developed the National Pollutant Inventory (NPI) in 1998. The council is a national body, which aims to ensure that all people in Australia enjoy equivalent protection from air, water, soil and noise pollution. It also aims to ensure that Australian markets are not distorted by variations in environment protection measures between the States and Territories.

The NPI was the first National Environment Protection Measure made by the National Environment Protection Council. The measure provides the framework for the establishment of the NPI. It sets out the requirements for reporting to the NPI, including how a facility triggers a reporting obligation and what substances are on the reporting list.

The Commonwealth, States and Territories are cooperatively implementing the NPI. An agreement called a Memorandum of Understanding (MOU) relating to the implementation of the NPI measure has been developed and signed by the Commonwealth, State and Territories ministers.

The NPI is used to record the types and amounts of pollutants being emitted by Australian industries so that this information is widely accessible to community, industry and government groups. An emission is defined as a release of a substance to the environment, whether in pure form or contained in other matter, and whether in solid, liquid or gaseous form. This information is stored in a public Internet database that displays information about the emissions from industrial facilities and diffuse sources of 90 different substances to air, land and water. The objectives of the NPI are to:

- Help industry and government with environmental planning and management
- Give the community up to date information about pollutant emissions from industrial facilities
- Promote waste minimisation, cleaner production, and energy and resource efficiency.

The NPI measure exempts some facilities from reporting to the NPI. A facility solely engaged in agricultural production or livestock raising is exempt. However, intensive livestock production such as beef cattle lot feeding must report. Other intensive livestock industries that must report include pig farming and poultry raising (meat and eggs). The Department of the Environment and Heritage define a beef feedlot as a confined area with watering and feeding facilities where cattle are completely hand or mechanically fed for the purpose of production (ARMCANZ 1997). Feedlot operations involve a number of activities including feed storage and distribution, feeding systems, animal housing, disposal of biological matter, waste removal/storage and waste treatment. Hence, the process of NPI reporting is an important consideration for the Australian Lot Feeders Association (ALFA).

An NPI handbook was designed to assist industries in reporting their emissions to the NPI database. This handbook contains an NPI guide and the required Emission Estimation (EET) Manuals. The NPI guide is a general guide to assist in determining the requirements for reporting emissions of listed substances to the NPI. It lists the substances and associated thresholds that trigger the requirement to report. Comprehensive information on estimating emissions to determine if threshold levels are exceeded is contained in the EET manuals. The feedlot EET manual provides the reporters to NPI the technical information required to complete their annual return and forms that basis for the simplified reporting form used by many feedlot reporters.

The NPI guide and manuals are available at:

http://www.npi.gov.au/handbooks/approved_handbooks/fbeef.html

The EET manuals are subject to continuous improvement and are therefore regarded as ‘live’ documents. The NPI guide for Intensive Livestock - Beef Cattle was first published in 1999 with Version 2 being released in February 2001.

4.2 Reporting Requirements

Each year, Australian intensive livestock production facilities that use any of the NPI listed substances must estimate and report their emissions directly to their state or territory environment agency if these emissions are estimated to exceed the NPI thresholds. The NPI listed substances are a broad range of substances typically present in materials used for production and currently there are 90 substances listed.

The complete list of the NPI substances that must be reported and the different categories and thresholds can be viewed and downloaded at www.npi.gov.au/nepm/substancelist.

The state and territory environment agencies review all NPI reports for accuracy and forward the data to the Australian Government. The reports are then displayed on the NPI public website http://www.npi.gov.au./.

4.2.1 Reportable Emission Sources

4.2.1.1 Transfers

Currently transfers of NPI listed substances do not need to be reported. Actions that are classified as transfers include discharges of substances to sewer, deposit of substances to landfill and removal of substances from a facility for destruction, treatment, recycling, reprocessing, recovery, or purification.

In beef cattle feedlots, NPI substances contained in water for on-site irrigation of effluent and wastewater are classified as emissions. Therefore reporting of emissions is required for any NPI-listed substances for which reporting thresholds are triggered. However, effluent and wastewater sent off-site for reuse by another facility is defined as a transfer and the emissions from this do not need to be reported by the dispatching facility. In this situation, the facility receiving these products must report the emissions if it is an industry that must report and if the use exceeds reporting thresholds.

4.2.1.2 Emissions to Air

Air emissions are categorised by the NPI as either point source or fugitive emissions. Point source air emissions are released through a single point such as a vent or stack. A facility may have multiple separate point sources.

Fugitive emissions are discharges that are not released via a stack or vent. Examples of some fugitive emissions are dust from stockpiles, volatilisation of vapour from open vessels, spills and materials handling. Emissions from ridgeline roof vents, louvres and open doors of a building, equipment leaks, valve leaks and flanges are other types of fugitive emissions.

Most emissions from beef cattle feedlots are fugitive emissions. This includes dust from pen areas, stockpiles, vehicle movements, bulk materials loading and transfer, vehicle exhaust emissions and NH_3 as a consequence of manure.

4.2.1.3 Emissions to Water

Emissions to water are defined by NPI as discharges to surface waters such as lakes, rivers, dams and estuaries, coastal or marine waters and stormwater runoff. This includes watercourses that only flow intermittently. As emissions of toxic substances to waterways may pose many environmental hazards, most state and territory environment agencies require facilities to closely monitor and measure these emissions. Data on emissions of nitrogen and phosphorus to waterways could be used as an input to LCA.

Feedlots are generally not permitted to release effluent or treated effluent to surface waters. Effluent is generally collected in holding ponds and used for irrigation or evaporated. It is likely that the only event that would cause such a release would be an unplanned situation such as extreme rainfall events or leaks/breaks in a holding pond wall. In this case, estimation of the total phosphorus (P) and total nitrogen (N) released would need to be undertaken to assess whether the Category 3 reporting thresholds are exceeded.

4.2.1.4 Emissions to Land

Emissions to land are defined by the NPI as substance emissions onto the facility’s site including solid wastes, slurries and sediments. Emissions to land from spills, leaks, storage and distribution of materials containing NPI substances may also occur. These emissions sources are broadly classified as surface impoundments of liquids and slurries. Unintentional leaks and spills must also be estimated and reported. It is not clear how this category of emissions would apply to feedlots.

4.3 NPI Reportable Emission Thresholds

Currently the NPI has five different threshold categories that separate the 90 listed substances into those resulting from production and combustion or other thermal processes. The categories are described in Sections 4.3.1-4.3.5. The thresholds are based on substance use, not substance emission. Each of the NPI listed substances has at least one threshold against it.

It is only necessary to report emissions of NPI listed substances if a facility exceeds the preset threshold of that substance within each category. That is, if a facility triggers a threshold for one Category 1 substance, the reporting requirement is for the emissions of that substance. If two Category 1 substances are used then emissions from both substances need to be reported.

The potential NPI reporting requirements for a beef cattle feedlot are described in the sections that follow.

4.3.1 Category 1

Category 1 covers a broad range of substances including most of the substances on the NPI reporting list. The listed substances are mostly present in materials used for production purposes and their threshold is 10 tonnes per year. This means that if a facility handles, manufactures, imports, processes or otherwise uses 10 tonnes or more per year of a Category 1 substance, then the emissions of that substance must be reported. The greenhouse gas substances - methane, nitrous oxide and carbon dioxide - -are currently excluded. Twelve common Category 1 substances, out of the total 90 Category 1 listed substances, are listed in Table 1.

4.3.2 Category 1a

Category 1a contains Total Volatile Organic Compounds (TVOC). The NPI defines TVOC as:

“Any chemical compound based on carbon chains or rings (and also containing hydrogen) with a vapour pressure greater than 2 mm of mercury (0.27 kPa) at 25°C. These compounds may contain oxygen, N and other elements. Substances that are specifically excluded are: carbon dioxide, carbon monoxide, carbonic acid, carbonate salts, metallic carbides and methane.”

The inclusion of TVOCs is intended to recognise the combined effect of compounds that contribute to smog formation that may not otherwise have been captured because individual substances do not meet a usage threshold in their own right. The most common sources of TVOCs emissions are from the storage and use of liquid and gaseous fuels, the storage and use of solvents and the combustion of fuels.

Table 1 – Selection of Common NPI-listed Category 1 Substances

Category 1	Category 1a
Acetone	Total Volatile Organic Compounds
NH3	
Arsenic & Compounds	
Benzene	
Carbon monoxide	
Chloroform	
Ethanol	
Hydrochloric acid	
Methanol	
Nitric acid	
Phosphoric acid	
Sulphur Dioxide	

Most fossil fuels consist mainly of a mixture of a number of different carbon compounds. In many fuels, some of these carbon compounds will meet the above VOC definition while others will not. There is a range of other substances in fuels that are not carbon compounds.

Further information about the composition of fuels can be found in the NPI Emission Estimation Technique Manual Fuel and Organic Liquid Storage on the web.

(www.npi.gov.au/handbooks/approved_handbooks/fols.html).

Category 1a thresholds are:

- use of 25 tonnes or more per year of TVOC; or
- a bulk storage facility that uses more than 25 tonnes per year **AND** has a design storage capacity greater than 25 kilotonnes (25,000 tonnes) of material containing VOC.

This threshold is tripped if a facility uses 25 tonnes or more of TVOCs in the reporting period. For example, if a facility uses 300 tonnes per year of a fuel that consists of 10% TVOCs by weight, then it is said to use 30 tonnes (300 x 10/100) of VOCs and hence exceeds this threshold.

There is one exemption to this definition. For bulk storage facilities, the threshold is only exceeded if their design capacity also exceeds 25 kilotonnes (25,000 tonnes). It is important to note that this only applies to facilities solely engaged in bulk storage and hence is not applicable to beef cattle feedlots.

Many feedlots will trigger the 10 tonnes per year limit for use of NH_3. NH_3 ‘use’ is generally the co-production of NH_3 as a by-product of cattle manure and in this case ‘use’ of NH_3 is an approximation of the NH_3 emission. NH_3 ‘use’ may also result from fertiliser use.

Most of the other substances listed under Category 1 and 1a have extremely limited use as inputs into the beef cattle feedlot industry. Only small quantities of chemicals are used for cleaning and veterinary purposes and it is unlikely that these substances would exceed the 10 tonnes per year Category 1 NPI reporting threshold.

Fuel use and bulk storage would not be expected to exceed the 25 tonnes or more of TVOC.

4.3.2.1 Category 1 Threshold Calculation

The first step is to identify which reportable NPI substances (predominantly NH_3) are used and to determine whether the amounts used or handled exceed the threshold values that trigger reporting requirements.

Since NH_3 'use' is generally the co-production of NH_3 as a by-product of cattle manure (faeces and urine), its use must be estimated since it cannot be directly measured. To estimate the amount of NH_3 produced, a series of steps needs to be undertaken.

Step 1

The amount of NH_3 produced per standard cattle unit (SCU) needs to be estimated. This can be calculated by:

Amount of NH_3 produced = Total N x fraction volatilised x fraction of NH_3 in N (Molecular Weight_{NH3}/Elemental Weight_{N}) - Equation 1

Where:

Total N is the mass excreted in kg N/SCU/year. The default value listed in the feedlot EET manual is 75 kg N/SCU/year and this value is derived from the American Society of Agricultural Engineers Standards (ASAE D384.1 - Manure production and characteristics, ASAE 1999) and the Livestock Waste Facilities Handbook (Midwest Plan Service 1985). If site-specific manure data is available for total N excretion then this value should be used.

Fraction volatilised is the percentage of N volatilised from the manure. The default value used is 90%. This value was calculated from component volatilisation rates shown in Table 4 and assumes that the NH_3 emissions consist of losses from fresh manure, feedlot pad, manure stockpile, holding pond and irrigation of effluent on-site. The percentages shown in Table 4 are sourced from the Livestock Waste Facilities Handbook (Midwest Plan Service 1985).

Molecular Weight_{NH3} = 17, and

Elemental Weight_{N} = 14

Using the default excretion value of 75kg N/SCU/yr, then the amount of NH_3 produced per SCU is:

75 x 0.9 x 17/14 = 82 kg of NH_3 per SCU per year or 0.08196 tonnes of NH_3 per SCU per year

To determine the annual amount of $NH_{3:}$

Total NH_3 produced = Herd capacity (SCU) x Annual NH_3 produced per SCU - Equation 2

Based on the default value of 75 kg N/SCU/year total N excretion, the minimum herd capacity to trigger the Category 1 threshold is:

Minimum herd = 10 tonnes of NH_3 / 0.08196t of NH_3 per SCU per year = 122 SCU - Equation 3

Herd capacity should be based on number of cattle on feed rather then licensed capacity or pen capacity since this is the capacity that contributes to emissions. In some cases (100% occupancy), the number of cattle on feed may equal licensed or pen capacity. However, as a long-term average, feedlots operate at about 70-80% occupancy. Hence, the use of licensed pen capacity in NPI calculations would over-estimate emissions.

Latest statistics show that there are currently 674 AUSMEAT accredited feedlots in Australia representing a total capacity of approximately 1,101,608 cattle. Of these feedlots, 501 have a capacity exceeding 100 head and 123 have a capacity exceeding 1000 head (ALFA 2005).

Therefore most feedlots (about 500) should be reporting at least Category 1 NH_3 emissions to air. Currently on the NPI database, only 93 facilities are listed as having reporting NH_3 emissions. Of those 93, only 8 facilities report emissions of substances other than NH_3. This apparently low level of reporting compliance would indicate that NPI data would not be a sound source of environmental data for LCA analysis.

4.3.3 Category 2a

Category 2a covers a group of substances that are common products of combustion or other thermal processes. This category contains substances such as oxides of N and carbon monoxide.

Category 2a thresholds are:

- A facility burns 400 tonnes or more of fuel or waste per year; or
- A facility burns 1 tonne or more of fuel or waste per hour.

4.3.4 Category 2b

Category 2b also contains a group of substances that are common products of combustion or other thermal processes. It contains a range of trace metals that are emitted when large quantities of fuel are consumed, especially coal and oil.

The Category 2b thresholds are:

- A facility burns 2000 tonnes or more of fuel or waste per year; or
- A facility uses 60 000 megawatt hours (MWhr) or more of energy in a year; or
- A facility’s maximum potential power consumption is rated at 20 megawatts (MW) or more at any time during the year.

Table 2 illustrates the approximate volume of the different fuel types required to trigger Category 2 thresholds.

Table 2 – Approximate Fuel Usage Required to Trigger Category 2 Thresholds

Fuel Type	Category 2a	Category 2a	Category 2b	Fuel Density	Calorific Value
	Yearly	Hourly	Yearly		
Diesel (L)	478,000	1200	2,390,000	0.836 kg/L	38.2 MJ/kg
Petrol (L)	541,000	1350	2,710,000	0.739 kg/L	34.4 MJ/kg
Natural Gas (MJ)	20,420,000	51,050	102,100,000	0.762 kg/m^3	38.9 MJ/m^3
LPG (L)	784,000	1960	3,920,000	0.51 kg/L	49.6 MJ/kg
Solid Fuel (t)	400	1	2000	-	

Reproduced from Emission Estimation Technique Manual for Intensive Livestock – Beef Cattle – Table 2.

The first step is to determine whether the amounts of fuel used exceed the threshold values for Category 2a and / or Category 2b. This requires a number of steps as outlined.

Step 1.

The total quantity of each fuel used in the reporting year and the maximum hourly usage should be determined. This should be in tonnes (t) for solids (coal etc), litres (L) for liquids (diesel, petrol etc) and megajoules (MJ) for gaseous fuel (natural gas, LPG etc).

If a single fuel is used at a facility then the total quantity of fuel should be compared to the thresholds values for Category 2 substances. If more than 1 type of fuel is used by a facility, e.g. diesel and natural gas, then the combined weight of fuel must be determined to find whether the Category 2 thresholds are exceeded. This is completed by multiplying the amount of each fuel used by its density from Table 2. The weight of each fuel is then converted to tonnes and summed to find the total fuel usage.

Step 2.

The total quantity of fuel used should be compared to Category 2a and Category 2 thresholds. If Category 2a and 2b thresholds are not exceeded by yearly usage then the maximum hourly quantity should be compared to the Category 2a hourly use threshold to find if reporting is warranted.

4.3.5 Category 3

Category 3 substances are total N and total P. The threshold for Category 3 is based on the actual amount emitted rather than inputs.

Emissions of a Category 3 substance only need to be reported if they are discharged to rivers, creeks and other water bodies. Water bodies include watercourses that only flow intermittently. Feedlots are not permitted to discharge effluent to surface waters. Effluent is generally directed to holding ponds and wastewater treatment processes and the effluent from the ponds is generally used for irrigation purposes. Hence feedlots would not normally be required to report Category 3 substances. The only time this might happen would be if there was a major spill, perhaps as a result of a breach in a holding pond wall. More than 15 tonnes of total N or 3 tonnes of total P would need to enter a water body in a reporting year to trigger NPI reporting responsibilities. Using the NPI default holding pond concentrations of 720 mg N/L and 100 mg P/L, some 21 ML of effluent would need to enter a water body to trigger reporting for N and some 30 ML of effluent would need to enter a water body to trigger reporting for P. Hence, it is very unlikely that a spill would trigger the Category 3 reporting thresholds but an estimate of the total P and total N released should be undertaken to make a definitive assessment.

4.4 Emission Estimation

The emission estimations for the most relevant categories - Category 1 – NH_3 emissions and Category 2a and 2b are presented.

4.4.1 Category 1 Emission Calculation – Emissions to Air

If the threshold value for NH_3 use is exceeded then the total emissions of NH_3 must be estimated and reported to NPI. To estimate the total emissions of NH_3 the following steps are undertaken.

Step 1.

The individual activities conducted at the feedlot that contribute to NH_3 emissions should be identified. Only on-site releases of NH_3 need to be reported. This includes on-site irrigation of effluent. However emissions from off-site irrigation of effluent are classified as transfers and are not included. Table 3 should be used as a guide when determining individual activities.

Step 2

The estimation of emissions from each identified activity is then calculated separately. Estimation of emissions from each individual source is calculated by determining amount of N produced multiplied by the percentage volatilised multiplied by the amount of NH_3 in the volatilised N.

For each individual activity this can be calculated by:

Amount of N produced (kg N/year) = Herd Capacity (SCU) x N excreted (kg N/SCU/year) - Equation 4.

Herd capacity should be based on number of cattle on feed, rather then licensed capacity or pen capacity.

On-site data can be used to estimate N excretion via nutrient mass balance models such as BEEFBAL (QDPI&F 2005). If on-site data is not available then the default values of N excretion from Table 3 are used.

Amount of N volatilised = Amount of N produced x percentage volatilised - Equation 5

The percentage of N volatilised from each individual activity is shown in Table 4. This assumes that NH_3 emissions consist of losses from fresh manure, feedlot pad, manure stockpile, holding pond and irrigation of effluent on-site. The percentages shown in Table 4 are sourced from the Livestock Waste Facilities Handbook (Midwest Plan Service 1985).

Amount of NH_3 released = Amount of N volatilised x fraction of NH_3 in N (Molecular Weight_{NH3}/Elemental Weight_{N}) - Equation 6

The total amount of NH_3 released is the sum of the releases to air from each individual activity. This may also include NH_3 emissions from fertiliser use.

Figure 3 is a schematic model of the feedlot system illustrating individual activities that contribute to Category 1 (NH_3) and Category 2a and 2b emissions.

Table 3* – Default Emission Factors for Total N in Beef Cattle Feedlots

Component	Emission Factor (kg Total N/SCU/year)
Freshly excreted manure	75
Manure remaining on pad	24.6**
Run-off to retention pond	5.4

Reproduced from Emission Estimation Technique Manual for Intensive Livestock – Beef Cattle – Table 5.
**Approximately 18% of the freshly excreted manure (that has not been volatilised) is transferred to the retention pond as run-off. The 82% (that has not been volatilised) remains on the feedlot pad until it is scraped off.

Table 4 – Percentage of Total N Volatilised (as NH_3) from Various Stages of the Manure Management System

Source	% of Total N Volatilised from each source	NH_3 Emission Factor* Kg NH_3/SCU/year
Fresh Manure	60%	54.6
Manure remaining on pad	80%	23.9
Manure stockpile	30%	1.79
Retention pond	26%	1.709
Irrigation (on-site)	25%	0.219**
Soil (post irrigation)	25%	0.163**

* Reproduced from Emission Estimation Technique Manual for Intensive Livestock – Beef Cattle – Table 6 and Table 7.

** kg NH_3/SCU/kL water irrigated per SCU

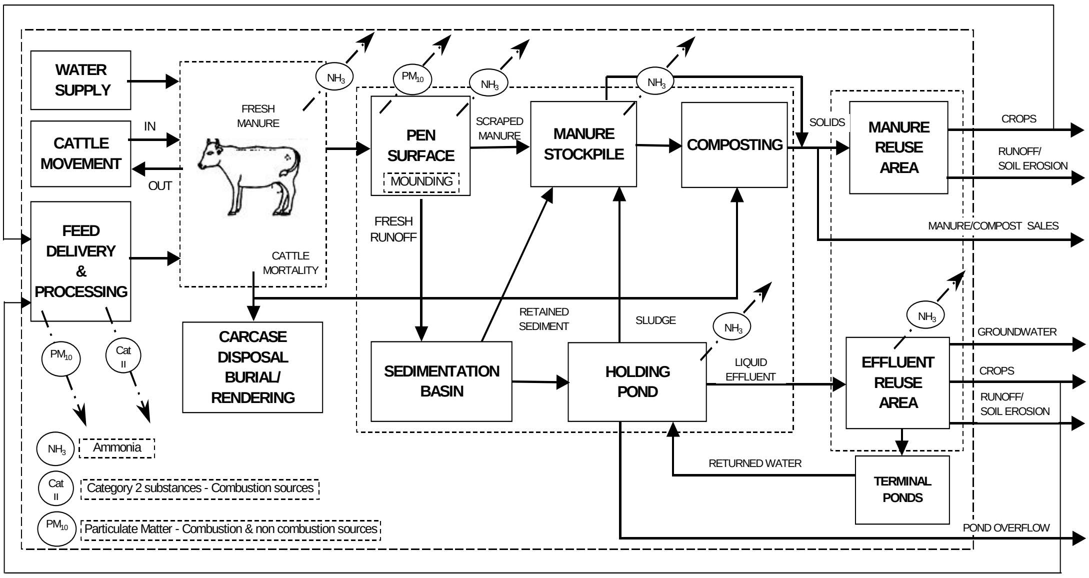

Figure 3 – Schematic Model of the Feedlot System for NPI Reporting

Example 1 – Calculation of NH_3 emissions

The feedlot operator has calculated that reporting is required for emissions of NH_3. The operator has an equivalent herd capacity of 10,000 SCU.

The activities at the facility that contribute to NH_3 emissions are identified as fresh manure, manure remaining on pad, stockpiled manure and holding (retention) pond. There is no irrigation of effluent on site. No site-specific data is available so the default data given in Table 3 and Table 4 are used.

Fresh Manure Losses

From Table 4, the NH_3 emission factor is 54.6 kg NH_3/SCU/year.

Annual amount of NH_3 produced = 10,000 SCU * 54.6 kg NH_3/SCU/year
= 546,000 kg /year of NH_3
= 546 tonnes /year of NH3

NH_3 Losses from the Pad Surface

From Table 4, the NH_3 emission factor is 23.9 kg NH_3/SCU/year.

Annual amount of NH_3 produced = 10,000 SCU * 23.9 kg NH_3/SCU/year
= 239,000 kg /year of NH_3
= 239 tonnes /year of NH_3

Manure Stockpile Losses

From Table 4, the NH_3 emission factor is 1.79 kg NH_3/SCU/year.

Annual amount of NH_3 produced = 10,000 SCU * 1.79 kg NH_3/SCU/year
= 17,900 kg /year of NH_3
= 17.9 tonnes /year of NH_3

Holding Pond Losses

From Table 4, the NH_3 emission factor is 1.709 kg NH_3/SCU/year.

Annual amount of NH_3 produced = 10,000 SCU * 1.709 kg NH_3/SCU/year
= 17,090 kg /year of NH_3
= 17.09 tonnes /year of NH_3

Total amount of NH3 released to air

Total NH_3 released = Fresh manure losses + *losses from the pad surface* + *manure stockpile losses* + *holding pond losses.*
= 546 t/year + 239 t/year + 17.9 t/year + 17.09 t/year
= 820 t/yr NH_3

A detailed worked example for calculating NH_3 emissions can be found in the feedlot EET manual.

4.4.2 Category 2a and 2b

If the threshold value is exceeded for Category 2a, then all Category 2a pollutants from all sources need to be reported. If the Category 2b threshold is triggered, Category 2a and 2b pollutants need to be reported. Table 5 lists the Category 2a and 2b substances. Emission sources include boilers and stationary and non-stationery combustion engines. Another source of particulate matter for the feedlot industry in particular is the release of PM_{10} dust predominantly from the pen area.

Techniques for estimating the emissions of Category 2a or 2b substances from fuel combustion are provided in the NPI EET manuals for Combustion in Boilers and Combustion Engines.

Techniques for estimating the emissions of Category 2a or 2b substances from non-combustion sources are provided in the NPI EET manuals for fugitive emissions. Feedlot facilities should report emissions from particulate matter dust (PM_{10}) if Category 2 thresholds are exceeded. Emission of PM_{10} dust is from the movement of cattle in the pen area.

The calculation of Category 2a and 2b emissions is complex and is not reported here. The complexity of these calculations probably inhibits the ability of lot-feeders to report these emissions.

Table 5 – NPI-listed Category 2a and 2b Substances

Category 2a	Category 2b
Carbon Monoxide	All Category 2a substances plus
Fluoride Compounds	Arsenic & compounds
Hydrochloric Acid	Beryllium & compounds
Oxides of N	Cadmium & compounds
Particulate Matter (PM_{10})	Chromium (III) compounds
Polycyclic Aromatic Hydrocarbons	Chromium (VI) compounds
Sulphur Dioxide	Copper & compounds
Total Volatile Organic Compounds	Lead & compounds
	Magnesium Oxide Fume
	Mercury & compounds
	Nickel & compounds
	Nickel Carbonyl
	Nickel Subsulfide
	Polychlorinated Dioxins & Furans

4.4.3 Category 3

The estimate of the total N and total P released to a water body is determined from the volume of overflow multiplied by the concentration of N and P in the effluent water.

The default values on total N and total P concentrations are 720 mg N/L and 100 mg P/L. If continuous monitoring of effluent concentrations from site-specific holding ponds is available, then these values should be used. The difficulty with undertaking these calculations is that it is almost impossible to estimate the volume of overflow (ML) if an event occurred.

4.5 Manure Nitrogen Excretion

4.5.1 Estimation of Manure Excretion – Live Animal Mass Approach

The feedlot EET manual provides a default value for total N excretion of 75 kg N per SCU per year (Table 3). This default value is derived from the ASAE Standards (ASAE 1999) and the Livestock Waste Facilities Handbook (Midwest Planning Service 1985) (Environment Australia 2001). It is based on fresh manure production and characteristics per unit of live animal mass per day.

Most nutrient excretion models (USEPA 2004) use the ASAE standards, which are based on the live body weight of the animals. ASAE standards data are a collation of published and unpublished information on livestock manure production and characterisation. Total manure production is based on the live body weight of animals.

Watts et al. (1994) investigated annual manure production and characterisation from feedlot cattle in Southern Queensland. In this work, it was assumed that manure production was linearly related to cattle live body weight. Annual manure data was based on a percentage of liveweight for different sized cattle and characterisation based on ASAE (1990) data.

Lott (1998) stated that “cattle excrete faeces and urine that when combined have a mass of equivalent to 5–6 % of the animals body weight. For a 450 kg steer approximately 27 kg of manure (faeces and urine) is produced every day. Of this, 24 kg is water and 3 kg is dry matter.” This is equivalent to 1095 kg total solids (TS)/head/yr and 8760 kg water/head/yr. This is about 1 tonne of dry matter per head per year.

Further research in the feedlot industry has raised questions on the validity of estimating manure excretions based on liveweight (van Sliedregt et al. 2000). In a study undertaken by Sinclair (1997), no relationship between urine and faeces production and liveweight was found. Since his study did not show increasing dry matter intakes with increasing liveweight (SCU), he also questioned the value of SCU for estimating manure production. He suggested that SCU (viz liveweight) did not influence manure production within the live weight range of 240 kg to 377 kg.

Van Horn et al. (1994) and Morse et al. (1994) also report no direct relationship between manure production and animal liveweight. Van Horn (1992) suggests that most nutrient excretion standards use ASAE standards and are based on the body weight of the animals. He found that for dairy cows this did not account for the effect of the variations in feeding level, voluntary feed intake, supplement levels and milk production on subsequent excretion levels. He concluded that excretion estimates based on dietary intake of a nutrient, minus amount secreted in milk was a good method for predicting total animal excretion of minerals by mature dairy cows and one on which to base manure management systems.

4.5.2 Estimation of Manure Excretion – Feed Intake Approach

In the last ten years, there has been significant development of the feedlot industry in terms of expertise and the specialist feeding of animals for specific markets. Concurrently there has been extensive research in the areas of animal growth and composition, the factors that influence feed intake and digestibility, feed composition and waste management.

Barth (1985) proposed a method called the Digestibility Approximation of Manure Production (DAMP) for predicting total solids (TS), volatile solids (VS) and fixed solids (FS) or ash of manure from a diet of known composition for any class of animal. The DAMP model uses the reported values of the percent total digestible nutrients (TDN) to calculate the inorganic and organic components of a ration available to the animal. The DAMP model requires as input the mass, percentage dry matter, percentage ash and percentage TDN of each feed component offered, and the level of feed wastage.

The Queensland Department of Primary Industries (QDPI) developed the Microsoft Excel©-based spreadsheet model BEEFBAL (QDPI&F 2005) to estimate the quality and quantity of manure produced by cattle feedlots and to assess the environmental sustainability of associated reuse practices (McGahan et al. 2002). BEEFBAL (QDPI&F 2005) provides a mass balance of the N, P, potassium (K) and salt entering the feedlot system (via incoming cattle, feed and drinking water) to determine the masses of nutrients and salt in the manure and liquid effluent produced by the feedlot. The model then uses this manure output data to assess the sustainability of the associated reuse areas. In assessing manure and effluent application rates, the model considers the nutrient uptake of the crop, the nutrient storage capacity of the soil and the expected nutrient losses to the environment (gaseous losses).

The original version of BEEFBAL (McGahan et al 2002) used a percentage of liveweight to estimate manure production. It included a simple mass-balance approach to manure production and, after details of ration type, daily feed intake and daily liveweight gain were considered, manure production was expressed as grams per kilogram of liveweight. This meant that for very large cattle, manure production was very high. Also, for long-fed cattle, there was a considerable change in manure production rates during their time in the feedlot.

However, in the past 20 years, research data has indicated that many factors influence the dry matter feed intake of ruminants, including weight, age, breed, sex, physiological state (e.g. pregnancy or lactation), frame size, body fatness, energy density of the diet, physical form and environmental factors such as heat or cold. Van Sliedregt et al. (2000) showed that a model including feed intake estimated from animal liveweight did not accurately predict manure production in feedlots. They showed that for most feeding ranges feed intake (and thus manure production) is reasonably constant with days on feed. In general, an animal requires between 2.7% and 3.0% of its liveweight as dry matter intake per day. Figure 4 shows a typical relationship between dry matter intake and days on feed for feedlot cattle (taken from van Sliedregt et al. 2000). These data show that, for most feeding ranges, feed intake is reasonably constant with days on feed. This is contrary to previous assumptions used to predict manure production.

The prediction of waste excretion using animal liveweight neglects two important factors likely to affect waste output, the digestibility of the diet and the feed intake of the animal (van Sliedregt et al. 2000). The digestibility of a whole diet has been proposed as a way of predicting the TS, VS and FS or ash excreted by an animal.

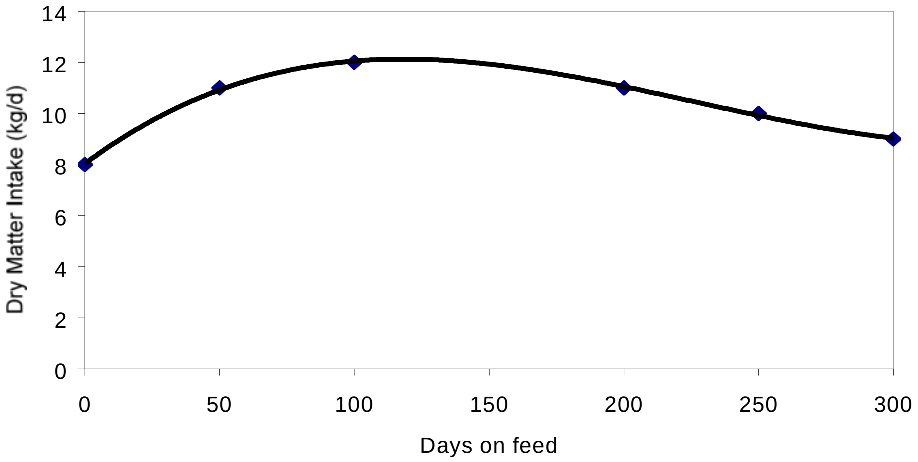

Figure 4 – Relationship Between Feed Intake and Days on Feed (van Sliedregt et al. 2000).

The digestibility of feed is defined as the proportion that is not excreted in the faeces and which is absorbed and utilised by the animal, and is closely related to its chemical composition. Grains show far less variation in composition (Dry Matter Density (DMD) range 70 - 95%) than forages (DMD range 20 - 80%). Knowing digestibility and hence indigestibility of the diet dry matter and organic matter permits estimation of the amounts of dry matter and organic matter excreted in faeces, components that determine manure quantity (Powers & Van Horn 1998). Urine is the avenue of excretion for several metabolic end products, most importantly urea, K and sodium. Excreted P and calcium and slower-released N from undigested protein primarily are in the faeces (Powers and Van Horn 1998).

The concentration and form of N in the diet can affect the quantity and form of N excreted by beef cattle (Cole et al. 2003). The grains most commonly used in Australian diets are sorghum, wheat and barley. Many studies have concluded beef cattle excrete more grain in faeces if grain is fed whole and without roughage. In Australian feedlots, methods including dry rolling, tempering, steam flaking and reconstitution are commonly used to treat grain to increase its digestibility and improve feed conversion efficiency, live weight gains and animal health.

Van Sliedregt et al. (2000) suggested that a more accurate model for predicting feedlot cattle excretion should be based on feed intake, feed digestibility and mass balance principles. These principles estimate the quantity of nutrients and salt in effluent and manure as the difference between inputs (cattle, feed and water) and outputs (cattle and N volatilisation).

4.6 Nitrogen Volatilisation

A detailed review of N volatilisation is contained within the Part C Report – Nutrient Cycling in Australian Feedlots. Consequently, the following sections provide a summary assessment of estimated N volatilisation losses from components of the feedlot manure management system. These include the feedlot pad, the effluent retention pond, the effluent irrigation process, the manure stockpile and the manure spreading process.

Table 4 provides the percentage of total N volatilised (as NH_3) from various stages of the manure management system along with the respective estimated NH_3 emission factor. NPI default values estimate that 90% of the total N excreted is volatilised.

4.6.1 Nitrogen Volatilisation from the Feedlot Pad

From the time manure is voided from the animal until it is spread on land, significant reductions in the N content of manure occur. N excreted by cattle is in both organic and inorganic forms. The organic forms are primarily contained in the faeces and typically comprise 50% protein N and 50% ammonium (NH_4) N. Mineralisation of faecal protein N occurs mainly through the activity of proteolytic and deaminative bacteria, initially hydrolysing proteins to peptides and amino acids and finally deamination to NH_4 (Gardner et al. 1994). This process occurs at a far slower rate than hydrolysis of urea (Varel, Nienaber & Freetly 1999).

The other major pathway of N excretion is via the urine. Urine contains 60–80 % of the total N excreted. About 70 % of the N in urine is urea and about 30% is readily mineralised organic compounds. Urea is hydrolysed by the enzyme urease, found in the faeces, to NH_4 and bicarbonate ions. Hydrolysis occurs rapidly, with complete conversion of urea N to NH_4 possible within a matter of hours, depending on environmental conditions (Muck & Richards 1980). The NH_4 is potentially available for gaseous loss to the atmosphere. Gardner et al. (1994) suggests that all of the N contained in urine is lost by volatilisation because pen manure has a poor pH buffering capacity and Cation Exchange Capacity (CEC) and because the cattle create increased temperatures within the pen. Gardner et al. (1994) assumed that there is no loss of N due to denitrification because the feedlot pad is an aerobic environment.

Koziel et al. (2005) measured NH_3 flux from fresh urine and faeces throughout a day. The cumulative NH_3–N emissions from urine were 13.7 % of NH_3–N compared to 2.5 % from fresh faeces. Other studies suggest 23-80 % of the N in fresh manure is lost in a very short time (Muck & Richards 1983; Safley, Westerman & Barker 1985, Bierman et al. 1995).

The level of dietary N may affect the N content of the feedlot pad manure. With feedlot cattle, McGinn et al. (2002) demonstrated a positive relationship between the level of intake protein and the NH_4–N content of surface sampled pen manure. Pandrangi et al. (2003) found that increasing the protein concentration in the diet increased potential NH_3 emissions. The source of crude protein fed to cattle had little effect on NH_3 emissions.

Another factor that significantly influences NH_3 volatilisation is temperature (Bunton 1999, Dewes 1996). Dewes (1996) evaluated temperature effects on N losses and concluded that almost all (99%) was lost within 4 days when temperatures were above 40^oC. Power, Eghball and Lory (1994) reported that little N may be lost with daily temperatures below 5 ^oC but 40- 60% of total N contained in manure can be lost through NH_3 volatilisation between 5 ^oC and 25^oC.

For Australian conditions, the percentage of total N volatilised from fresh manure and from the pen surface could range from 60% to almost 100%. Some 60-80% of all N is in the urine and most of this is likely to be rapidly lost. Additionally some of the faecal N would be lost.

4.6.2 Partitioning of Pad Manure Between Effluent and Harvested Manure

The N in manure remaining on the feedlot pad after volatilisation losses has two possible fates. Firstly it may be harvested during pen cleaning and taken to a stockpile or composting area. Secondly, it may be washed from the pen and collected in effluent holding ponds during rainfall events.

The concentration and quantity of N entering the effluent pond depends on the initial N concentration of the runoff, the surface hydraulics of the feedlot, the settling efficiency of the sedimentation basin and the particle size distribution of the eroded manure. The predicted runoff for any rainfall event is the cumulative total of the runoff from the pens and other areas within the feedlot catchment area. A study by Manges, Schmid and Murphy (1971) concluded that higher runoff rates produce lower N concentration in runoff. In addition, when runoff was samples from a runoff event that occurred shortly after another runoff event, the concentration of N increased because wetting from the first event and raindrop impact caused manure particles to go into suspension.

Gilbertson et al. (1971) reported N and P losses in runoff from feedlots and found that 8% of total N was diverted to liquid runoff in summer compared to 40% in winter. The work of Gilbertson et al. (1971) is unlikely to accurately reflect the current situation as feedlot design standards and manure management of Australian feedlots has improved dramatically over recent years, resulting in far less manure available for export to the ponds. Predictions of N loss rates from feedlot pads using BEEFBAL (McGahan 2002) indicate that about 3% of the excreted N is exported to the settling basin and retention pond in runoff.

4.6.3 Manure Stockpile or Composting Area

Manure collected from Australian feedlots is commonly stored in compacted stockpiles or is composted in windrows (Powell 1994; Powell 1996). Stockpiled and composted manure is more friable, with smaller particles (Raviv et al. 1987) compared to fresh pen manure and can be more evenly spread over land areas. Manure storages vary tremendously in their ability to conserve N. Temperature, moisture, pH, and C:N ratio are important in determining the amount of N lost from the manure (Eghball & Power 1994).

Manure stored in compacted stockpiles is subject to anaerobic decomposition, which generates a substantial amount of heat (Sweeten 1989). Current data suggests that stockpiled manure has over 90% of the total N in the organic form, while the remainder is in the inorganic NH_4-N or nitrate-N forms. NH_4-N levels are generally less than 5% of the total N. Stockpiling provides potential reductions in bulk, odours, weed seed viability and disease organisms. However, it does allow the gaseous loss of N, an increase in NH_4 concentration and leaching of other nutrients (McCalla, Peterson & Lue Hing 1977; Powell 1996). Photograph 1 illustrates a typical manure stockpile.

The variation in moisture, total N concentration between fresh pen samples and stockpiled samples from southern Queensland lots is shown in Table 6. Moisture variation of manure is dependent upon climate, age of manure, and storage conditions (Lott 1995). Powell (1994) states the rate of N loss is slightly higher than the loss of total dry matter in the stockpile. Furthermore, mass balance calculations suggest that the N loss from the stockpile can range from 15% to 40% due to variations in moisture content, temperature and C:N ratios.

Table 6 – Comparison of Composition of Pen Fresh and Stockpiled Manure from Southern Queensland Feedlots (Adapted from Lott 1995)

	Pen Fresh	Stockpiled
Number of samples	40	53
Moisture %	34	24
Total N %	2.37	2.03

Alternatively, manure stored under predominantly aerobic conditions (or actively composted) results in greater water loss (Powell 1994) and decomposition of cellulose and fibre (Follett & Croissant 1990). Power, Eghball and Lory (1994) estimated up to 25% loss of N due to volatilisation, which is within the range (20–40%) recorded by Eghball and Power (1994) during the composting process.

Photograph 1 – Manure stockpile (composted and screened manure)

4.6.4 Holding Ponds

There is little experimental data on NH_4 volatilisation rates from Australian feedlot holding ponds. Photograph 2 illustrates a typical feedlot holding pond. The reported range of values for runoff quality in holding ponds is both broad and variable within and between feedlots and difficult to predict. In the absence of published Australian data the greatest challenge remains the prediction of runoff quality. Atzeni, Casey and Skerman (2001) highlighted the rate of N volatilisation as an area requiring further research.

The combination of increased runoff, climatic factors (rainfall and evaporation) and manure management practices that allow for greater mineralisation of manure on the pad mean that the characteristics of US feedlot effluent are different from those of Australian feedlot effluent. Generally, effluent produced in Australia contains a lower N concentration (Table 7) than effluent derived from feedlots in the US. In addition, in some Australian lotfeeding regions, high rainfall levels significantly dilute the effluent stored in feedlot retention ponds.

Table 7 – Effluent Composition for US and Australian Feedlots

Component	Concentration	
	United States	Australia
Total N (mg/L)	721 (286-1155)	480 (50-500)

Note: The range is shown in parentheses.

Sweeten and Wolfe (1994) found that well-maintained settling ponds produced a total N removal efficiency of 14-24%. Culley and Phillips (1989) observed that liquid storages can lose approximately 33% of the N by volatilisation. Madden and Dornbush (1971) estimated potential N of around 35%.

Photograph 2 – Typical Feedlot Holding Pond

4.6.5 Manure Reuse

Fresh manure, stockpiled manure or composted manure is typically spread on cropped or pastured land. Numerous methods are used to apply and incorporate manure and N loss varies widely depending on the method used. The most common method is broadcast spreading. Photograph 3 illustrates a typical manure spreading operation.

Rotz (2004) suggests that solid cattle manure loses some 20% (8–60%) of the initial total N applied through NH_3 volatilisation, 1–25% as NO_3 and <1–4% as N_2O. N can be lost through surface runoff but this is generally quite low (<3% up to 10%). Surface spreading of manure without soil incorporation often ensures the loss of all remaining inorganic N (typically 20-40% of remaining N). Rapid incorporation decreases this loss by at least 50% (Rotz 2004) and by up to 98%; Svensson 1994).

Photograph 3 – Typical Manure Spreading Operation

4.6.6 Effluent Reuse

Most N losses during irrigation are due to NH_3 volatilisation. The type of irrigation system used affects the volatilisation rate. An irrigation system producing small droplets may produce higher volatilisation rates, because of the greater total surface area of the droplets. However, Chastain and Montes (2004) conducted an assessment of NH_3 volatilisation losses during sprinkler irrigation (travelling gun, centre pivot and impact sprinkler) for dairy, swine, and beef effluent. Total ammonical N (TAN) (NH_3–N + NH_4–N) collected on the ground did not differ from that collected from irrigated wastewater.

Volatilisation of N may be decreased by acidifying slurry (Frost, Stevens & Laughtlin 1990; Pain et al. 1990), injection into the soil, or the use of NH_3 inhibitors. Studies in Northern Ireland have indicated that the injection of animal slurries into the soil offers improved nutrient management over surface application, by reducing losses of gaseous N (Thompson & Pain 1987; Long & Gracey 1990) and reducing coating and scorching of herbage by slurry (Prins & Snijders 1987; Long & Gracey 1990).

In a literature summary of NH_3 volatilisation losses during irrigation, Chastain and Montes (2004) found NH_3 loss ranged from 2.5% to 13% with an overall mean of 4% of the TAN applied. Other studies (Westerman, Huffman & Barker 1995; Safley, Barker & Westerman 1992), have reported volatilisation losses of 10–18 % during irrigation of liquid swine manure.

Smith et al. (2001) reported NH_3 losses from overseas research ranging from 14-38% for piggery effluent reuse. Research by Smith et al. (2001) using piggery effluent on a winter and summer crop rotation in south-eastern Australia showed that about 12 % of the total N was lost by NH_3 volatilisation.

This research studied a centre-pivot irrigator applying 18 mm of effluent every three days. The irrigator operated 24 hours a day. When these losses were split into daytime and night time losses, they corresponded to 21% and 3% respectively. Night time effluent irrigation is not regularly practiced for intensive animal operations in Australia, being discouraged from an odour dispersion perspective.

Smith and Snow (2001) also studied the loss of N from an overland flow system. They found that at least 48% of the N from the piggery effluent applied was lost by either volatilisation or denitrification.

4.6.7 Soil (Post Irrigation)

Klepper et al. (2001) reported that nutrients in feedlot manure remain unavailable due to complexation and the form in which they are present, until the manure is mineralised and nutrients are released in the organic form. The low recovery of N, P and sulphur derived from manure is due to the slow mineralisation rate with N being the most limiting factor.

Nutrients derived from manure applications can be used by the plants or lost by NH_3 volatilisation, nitrate leaching, N runoff and N emissions that result from nitrification and denitrification processes. The greatest loss generally occurs through NH_3 volatilisation.

The N forms available for plant uptake are the inorganic forms: NH_4^+ and NO_3^-. Other inorganic N forms include NH_3, nitrous oxides (N_2O, NO) and dinitrogen (N_2). All the other forms reflect transformation or loss processes (Gardner et al. 1994). Processes that involve releases of NH_3, i.e. urea transformations, are of most interest in this work.

N applied to the soil as effluent and manure can undergo a number of transformations including:

- Mineralisation – the decomposition of organic N to NH_4 (NH_4^+).
- Immobilisation of inorganic forms of N by plants and micro-organisms to form organic N compounds
- Nitrification – the oxidation of NH_4 (NH_4^+) to nitrite (NO_2) and then into nitrate (NO_3).
- Denitrification of nitrate (NO_3) to nitrous oxide and N gas.
- Hydrolysis of urea into the NH_4 (NH_4^+) form.

Figure 5 shows the N pathways of effluent (or manure) on reuse areas. Each of these pathways is discussed in further detail below.

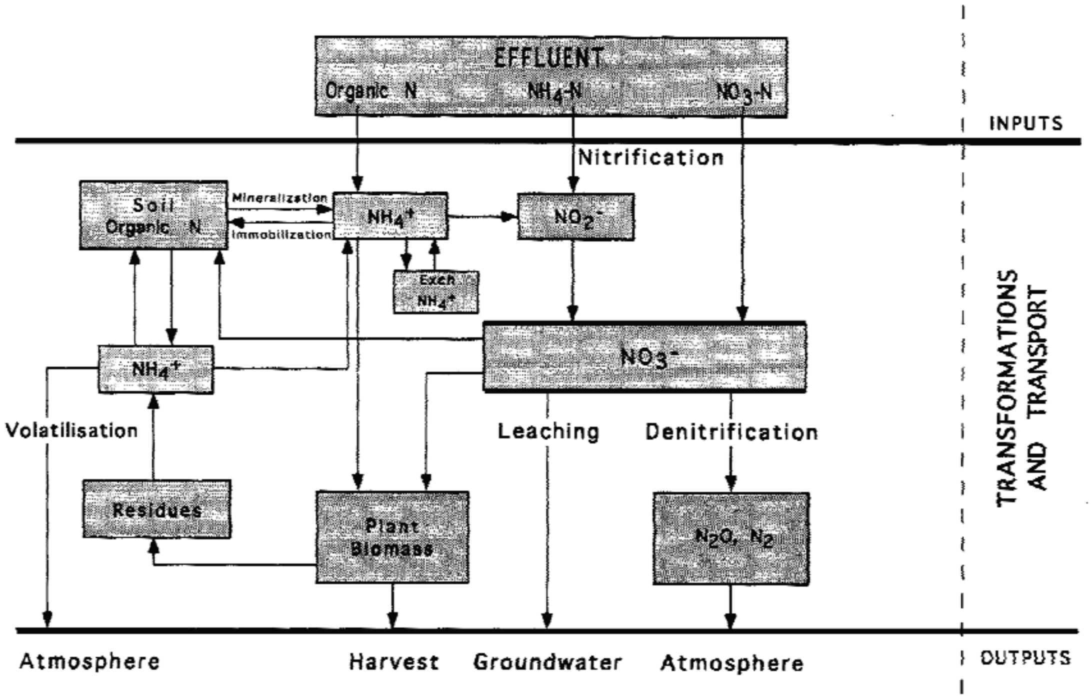

Figure 5 – Nitrogen Pathways of Effluent in Land Reuse Areas (Gardner et al. 1994)

The rate and amount of NH_3 loss depends upon weather conditions (temperature, wind speed, precipitation), manure characteristics and the properties of the soil to which the manure is applied. The N loss rate increases exponentially with temperature (Sommer, Olesen & Christensen 1991) and up to a wind speed of 2.5 m/s (Rotz 2004). Precipitation and soil properties and conditions also affect NH_3 volatilisation rates (Meisinger & Jokelo 2000). Stewart (1970) showed that both nitrification and NH_3 volatilisation were higher at higher soil pH levels. Peters and Reddell (1976) reported 10% of the total N applied as cattle manure was volatilised from a soil with pH 7.5, compared to a 20% volatilisation loss from a soil of pH 12. At a higher pH there is a greater degree of cation saturation on the exchange complex and thus less adsorption of NH_4^+. As well, the presence of OH^- favours the volatilisation of NH_4^+. Peoples, Frenzy and Mosier (1995) reported that NH_3 losses from animal wastes ranged from 0- >50% of the N applied to various cropping systems and from 9-33 % of the N when applied to grasslands.

5 Data Collection and Analysis

5.1 Data Survey

As part of the FLOT.328 project, a detailed survey of feedlot inputs and outputs was undertaken.

A wide range of data was collected but for this report, the relevant data included:

- Data on the number of incoming and outgoing cattle, intake and sale weights, dressing percentages and other parameters that allow HSCW gain to be estimated for two years (2002 & 2004).
- Diet ingredients (kg/yr), as-fed intake (kg/hd/day) and other parameters that allow N excretion to be estimated for two calendar years (2002 and 2004).

Most feedlots were able to provide good-quality data on incoming and outgoing cattle numbers, production and diet ingredients. Hence, it was possible to estimate annual N excretion in terms of average number of head on feed throughout year (SCU/year).

In this context, HSCW gain is the difference between total dressed carcass weights of cattle leaving the feedlot less the estimated total dressed carcass weight of cattle entering the feedlot.

5.2 Data Analysis

After data was entered into the survey by lot feeders various data quality checks were undertaken. Where anomalous data was detected, the participating feedlot was contacted and the data was examined in more detail. Next the data were entered into an enhanced mass balance model called the Feedlot Systems Analysis model (FSA model). Data input for this model included cattle numbers, market types, feed intake levels, diet ingredients and feed processing system. The FSA model incorporates a DAMP-based (digestibility approximation of manure production) method to determine the "as excreted" manure constituents, using a wide range of possible diet ingredients and market types. The FSA model also estimates N and P levels from various manure management components after excretion as per Figure 3.

The survey data indicated that feedlots have NPI reporting requirements associated with Category 1 - Emissions of NH_3, with all feedlots surveyed exceeding the threshold value of 10 tonnes of NH_3 per year. From the survey data input only one feedlot in the order of 25000 SCU capacity has reporting requirements for emissions to air associated with fuel combustion.

6 Results and Discussion

6.1 Estimation of Emission Factors

6.1.1 Nitrogen Excretion

Figure 6 illustrates the estimated total N excreted per SCU per year for the nine surveyed feedlots. These represent a cross section of the industry from small (1000 SCU), medium (7000 SCU) to large (25000 SCU) scale operations, spread geographically from Victoria to Queensland.

The default emission factor for freshly excreted manure on the pad is shown as a dashed horizontal line on Figure 6. From the available 2002 survey data, the estimated total N excreted per SCU per year ranges from 52 kg to 105 kg for freshly excreted manure. In 2004 estimated total N excreted per SCU per year ranges from 52 kg to 86 kg for freshly excreted manure. Excretion rates vary depending on the composition of processed diets that are complex in formulation and are subject to variation based on the availability and cost of various ingredients. Consider N excretion from Feedlot 4 in 2002. The main grains in the diet were maize, sorghum and barley, producing an excretion rate of 52 kg N /SCU per year. In 2004 less maize and more wheat was used in the diet leading to an increase in excretion rate to 67 kg/SCU per year. Other nitrogen sources in the diet may also have changed.

The estimation of manure N excretion should be based on feed intake methodology that provides a better estimate than estimates based on an animal liveweight basis. The estimate of 75 kg N/SCU/year provided in Section 3.2.1 of the feedlot EET manual overestimates by 10% the manure N excretion as estimated from mass balance modelling using typical Australian feedlot conditions for the nine feedlots surveyed. Partly this is because the literature is generally based on manure production estimated from animal mass and does not consider likely manure production based on feed intake. However, providing an accurate single generic N excretion factor for feedlot cattle is difficult because reported values for feedlot cattle excretion vary widely for TS, VS and N.

These results indicate that if default data is used for calculating NH_3 emissions in lieu of site-specific data then collectively the industry is probably overestimating its emissions.

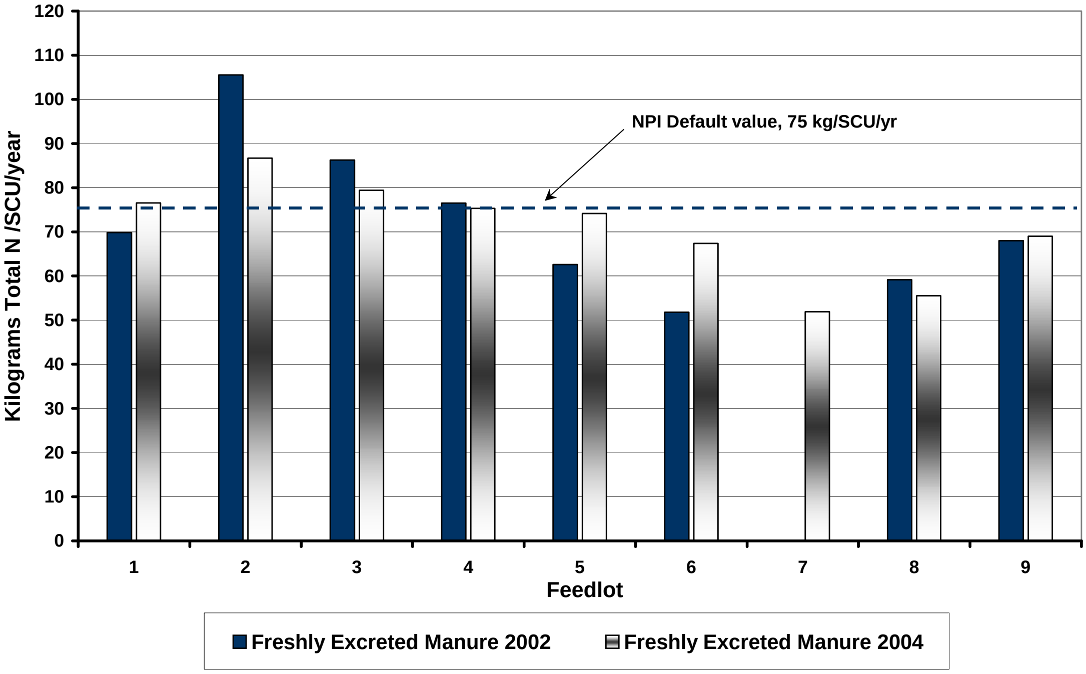

Figure 6 – Estimated Total Nitrogen Excreted per SCU per Year

6.1.2 NH_3 Volatilisation

From the available literature, N volatilisation rate from the feedlot pad was estimated at 80% of the N excretion rate. Hence, with an N excretion rate of 52-105 kg/SCU/yr, the N mass volatilised from the pad ranges from 42 kg/SCU/yr to 84 kg/SCU/yr leaving a range of 10-21 kg N/SCU/yr in the manure.

It was assumed that 3%, or a range of 0.3-0.63 kg/SCU/yr of the N remaining in the feedlot pad manure after volatilisation losses, is directed to the effluent retention pond. Of this, it is assumed that 30% or 0.09-0.19 kg/SCU/yr is partitioned to sludge. This is less than 0.5% of the N excreted. This leaves 70% of the influent N, or 0.21-0.44 kg/SCU/yr in the supernatant. Hence, 97% of N that does not enter the effluent retention pond, or a range of 9.7-20.4 kg/SCU/yr is harvested from the pad and stockpiled or composted.

Available literature suggests a loss rate in the order of 25% from manure stockpiles would be applicable for Australian conditions. Results from the survey indicate that the mass of N to the stockpile is estimated at 9.7-20.4 kg/SCU/yr. Hence, some 2.43-5.1 kg/SCU/yr will be lost leaving the remainder for spreading.

Data from the survey was input in the Feedlot Systems Analysis model to confirm that the estimated losses throughout the system produced realistic N concentrations in stockpiled manure and in holding pond effluent. The results showed an average stockpiled manure N concentration of 2.2% and a holding pond effluent concentration range of 250-420 mg N/L. Since stockpiled manure typically contains 2-2.2% N and retention pond effluent typically contains 330 mg N/L the estimated N losses to this point are realistic.

The NPI default values for N volatilisation assume that 90% of the total N excreted is volatilised. Total N emitted to the atmosphere from the data collected was found to average 88%. Despite using different processes to arrive at this total there was not a significant difference in the total N volatilised when compared with the NPI default values.

6.1.3 Category 2 – Emissions to Air Associated with Fuel Combustion

If a single fuel is used at a facility then the Category 2 threshold is exceeded if the quantity used exceeds the limits specified in Table 1. If the threshold level is exceeded for any fuel type then the total emission for all fuel types must be reported. Lot feeders need to be aware that if their facility is required to estimate Category 2 substances then this should include emissions from particulate matter dust less than 10 micron (PM_{10}) resulting from the movement of cattle in the pen area.

7 Conclusions and Recommendations

7.1 Conclusions

The National Pollutant Inventory (NPI) is used to record the types and amounts of pollutants being emitted by Australian industries, including cattle feedlots. If this data was accurate, the data could be used in LCA studies of the feedlot industry.

The majority of emissions from beef cattle feedlot facilities are NH_3 emissions resulting from N excretion in manure production with larger feedlots also required to report energy consumed or fuel used.

A summary of the methodology contained within the emission estimation technique manual for determining thresholds and estimating NH_3 emissions for Category I type substances is presented.

Factual information that allowed the estimation of N excretion levels for Australian feedlots across a range of climatic, size and management conditions was collected. N levels were determined using feed intake methodology that provides a better estimate over estimates based on an animal live weight basis. These levels were compared with the estimates of the default NPI reporting framework.

N excretion per SCU per year for freshly excreted manure ranged from 52 kg to 105 kg with a median value of 68 kg for the nine feedlots surveyed. N excretion was dependent on the composition of processed diets that are complex in formulation and are subject to variation based on the availability and cost of various ingredients.

Providing a single multiplier for estimating NH_3 emissions from all cattle feedlots is likely to provide a poor estimate of emissions because of variations in factors like:

- Class of stock fed (which influences protein and hence N inputs and outputs).
- Type of diet fed (high silage, high grain) and the grain treatment process.
- Pen surface treatments (pH modifiers, woodchip etc).
- Climatic zone (temperate, sub-tropical).
- Manure storage and / or treatment pre-spreading (e.g. spread fresh, stored pre-spreading, composted pre-spreading).

In this study, the NPI default estimate of 75 kg N/SCU/yr overestimates the manure N excretion as estimated from mass balance modelling based on data from nine surveyed feedlots. Partly, this is because the literature is generally based on manure production estimated from animal mass rather than feed intake. Also, providing a single generic N excretion factor for feedlot cattle as in the NPI is difficult because reported values for feedlot cattle excretion vary widely for N. It is also likely that there is a wide range in the NH_3 emission rate.

The modelled total N volatilisation from the system was similar to the NPI default values.

These results indicate that if default data is used in lieu of site-specific data for the calculation of NH_3 emissions then collectively the industry is potentially overestimating these emissions.

There are three sources for potentially overestimating NH_3 emissions from feedlots. These include using licensed capacity or pen capacity as the default herd capacity, using the default NPI N excretion value and using default NPI volatilisation rates for individual manure management components.

Most Australian feedlots (about 500) should be reporting at least Category 1 NH_3 emissions to air. Currently on the NPI database, only 93 facilities are listed as having reported NH_3 emissions. Of these 93, only 8 facilities report emissions of substances other than NH_3. This apparently low level of reporting compliance would indicate that NPI data would not be a sound source of environmental data for LCA analysis.

7.2 Recommendations

This study highlighted that the feedlot EET manual is a detailed and complex document. The NPI default N value probably overestimates the average manure N excretion as estimated from mass balance modelling using site-specific data. Whilst, the type and detail of the information collected in this study allowed evaluation of the total N excretion and relativity between market types and individual feedlot operations it highlighted that limited data is available on NH_3 volatilisation from various components of manure management systems.

Hence, recommendations for further research include reviewing and simplifying the NPI feedlot EET manual including clarity of terminology (e.g. herd capacity) and review of the accuracy and currency of providing a single N excretion value and NH_3 emission factors or alternative methods for reporting NH_3 emissions.

The development and adoption of an empirical formula incorporating different factors for various location, design and management parameters would provide a far more accurate and powerful tool for estimating NH_3 emissions from individual feedlots. The different factors for each parameter could be revised as new research data becomes available.

Due to the low level of reporting compliance, it is not recommended that NPI data be used in feedlot LCA studies.

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Environmental Sustainability Assessment of the Australian Feedlot Industry

Part E - Review of Lot Fed Cattle Water

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Abstract

Drinking water is vital for the health, welfare and productivity of lot fed beef cattle. Limited theoretical or actual data regarding cattle water consumption under the range of different conditions encountered at Australian feedlots is available. This report reviews literature pertaining to beef cattle water consumption and experimental work undertaken in Australian feedlots. Predictive water consumption models are compared and their suitability for Australian conditions is discussed. Water consumption data collected from Australian feedlots is reviewed and the main factors influencing water consumption are examined.

Executive Summary

Water is a fundamental requirement for beef cattle feedlots. In Australia, an adequate, reliable supply of quality water is needed to obtain a licence to operate a feedlot. Substantial quantities of water are used at feedlots, mainly for drinking by cattle, but also for feed processing, washing cattle before their dispatch for processing, trough cleaning, system spillage and evaporation, staff amenities and effluent irrigation dilution. As drinking water is the main component of feedlot water usage, the industry will continue to use substantial quantities of water into the future.

Current trends suggest that water will be increasingly valuable due to limited supply and higher water charges (through increasing cost recovery from water supply schemes or the inclusion of environmental factors in water pricing). Environmental sustainability is an increasingly important issue for the general public, and the water use efficiency of industries is particularly topical during the current drought conditions. A key factor for productivity and sustainability within any industry is benchmarking and continuous improvement in performance.

This report provides an initial reference point for benchmarking lot fed cattle water consumption. Literature relevant to feedlot cattle water consumption is reviewed, providing theoretical and experimental information and examining the factors influencing consumption. Predictive water consumption models are compared and their suitability for Australian conditions is discussed. Water consumption data collected from Australian feedlots is reviewed and the main factors influencing water consumption are examined.

The pattern of water consumption throughout the day was relatively consistent across all treatments. Water consumption rates generally followed heat load index values, with minimal consumption between midnight and 6 am, peak consumption between 6 am and 8 pm and low consumption between 8 pm and midnight. Water consumption rates were higher during and following periods of high heat load index peak values (>90), with a more pronounced peak consumption period from 2 – 8 pm. Large variations in water consumption between 6-minute recording periods were observed throughout the day for all treatments.

The results of the water consumption trials show that shading, ambient temperature, rainfall and dry matter intake all influence water consumption across feedlots. The results indicate that shading reduces water consumption and generally reduces the length of peak water demand. The results also showed that parameters are inter-related, with climate (temperature and rainfall) influencing feed intake as well as water consumption. Insufficient data was available to determine how the parameters influenced each other.

Higher maximum daily ambient temperatures (>30^{O}C) were associated with large peak hourly water demands for unshaded pens, while shaded pens under the same temperatures had much lower peak demand. Lower maximum daily ambient temperatures produced larger peaks in hourly water consumption in shaded pens than unshaded pens, but similar peak rates of consumption (i.e. the peak hourly rate of consumption in unshaded pens was closer to the consumption rates throughout the day. The extent of changes in water consumption with a given change in climatic conditions (e.g. an increase in maximum daily ambient temperature of 5^{O}C) was not consistent over time, possibly reflecting the inter-relationships between parameters.

Water consumption models previously proposed by Sanders et al. (1994 – based on this data set), Hicks et al. (1988), and Watts et al. (1994 – based on results from Winchester and Morris) were compared to measured data and to each other. The analysis showed that the Sanders et al. (1994) and Hicks et al. (1988) models tended to under-estimate water consumption compared to the measured data. The Winchester and Morris model (using the *Bos indicus* data) tended to under-estimate water consumption for ambient temperatures <35^{O}C and over-predict water consumption at higher temperatures. All model results are generally within the range of measured data except for the Winchester and Morris model results for shaded pens.

The data was reviewed to determine if a simple relationship between daily water consumption and environmental factors could be found. The review found trends between daily water consumption and maximum daily temperature, however due to the limited data available no relationship could be confidently developed. The development of a simple model that can provide approximate water consumption estimates for locations where meteorological data is restricted would be of benefit to the Australian Industry.

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Acknowledgements

This report is a review of the work, and subsequent report, undertaken by the Queensland Department of Primary Industries (QDPI) Feedlot Services Team during 1993 and 1994 to examine the water consumption of lot fed cattle. The authors acknowledge and thank all who contributed to the water consumption trial and preparation of Report 12.A for Meat Research Corporation Report Project No DAQ.079, “Lot Fed Cattle Water consumption”.

Significant contributions were made during the experimental phase in the mid 1990’s by:

- Mr Des Rinehart: Manager, Lillyvale Feedlot
- Mr Kevin Roberts: Manager, Sandalwood Feedlot
- Dr Peter Watts: Executive Engineer, QDPI, Team Leader
- Mr Ken Casey: Executive Engineer, QDPI, Team Leader
- Ms Robyn Tucker: Beef Feedlot Husbandry Officer, QDPI
- Dr Simon Lott: Agricultural Engineer, QDPI
- Mr Paul Sanders: Agricultural Engineer, QDPI
- Ms Kate Lyndon: Undergraduate student, University of Queensland.
- Dr Barry Norton: Associate Professor, University of Queensland.
- Mr Chris Lunney: Technical Assistant, QDPI statistical analysis
- Mr Brian Rolfe: Technical Assistant, QDPI for processing of meteorological data
- Mr Dave Butler: Biometrician, QDPI statistical analysis
- Ms Tanzi Smith: Administration Officer, QDPI processing of water consumption data
- Mr Troy Jensen: Agricultural Engineer, QDPI for installation and servicing of site equipment
- Mr Bill Town: Agricultural Engineer, QDPI for installation and servicing of site equipment

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1 Background

The Australian red meat industry, as with most primary industries, is coming under increasing pressure from both the community and government to document and justify its impacts on the environment and its use of natural resources. This is evident through the government emphasis on industry initiatives such as the implementation of Environmental Management Systems (EMS) and Triple Bottom Line (TBL) reporting requirements. Currently, a lack of credible supply chain data prevents the industry from being able to respond in a meaningful manner.

Meat and Livestock Australia (MLA) is undertaking a project (COMP.094) that will address these issues and provide credible data on the industry's environmental impacts and sustainability for use by industry, including its interactions with government, community groups and the media. This project will use the standardised tool, Life Cycle Assessment (LCA), to quantify natural resource consumption and environmental interventions to water, soil and air.

A separate but related project (FLOT.328) is being undertaken for the lot feeding sector of the Australian red meat industry.

1.1 FLOT.328 Project Description

As part of the overall industry project (COMP.094), the beef cattle lot feeding sector is undertaking a related project (FLOT.328) that will contribute to the whole of industry dataset, but more importantly will address the public misconceptions of the environmental sustainability of the feedlot industry by identifying and quantifying the environmental costs associated with the production of one kilogram of grained beef compared to its domestic competing products (grass fed beef, lamb, pig and poultry meats).

Given that environmental sustainability will eventually become a key element in maintaining and improving access for Australian product into key overseas markets, it is envisaged that the project will also benchmark these costs against international competitors (US and European beef) and identify areas of R&D investment to ensure the long-term viability and sustainability of the feedlot production system.

2 Project Objectives

The FLOT.328 project will:

1. Collect, collate and present relevant data to enable MLA to assess/benchmark the environmental sustainability of the feedlot industry against its domestic and international competitors by assessing the environmental costs associated with the production of one kilogram of meat from each production system.
2. Provide data for the feedlot industry suitable for use within the broader red meat supply chain Life Cycle Assessment (COMP.094).
3. Identify areas for potential future R&D investment to ensure long-term competitiveness, viability and sustainability of the feedlot production system.
4. Communicate the results of the assessment to MLA in a format suitable for dissemination to industry stakeholders.

This report provides a review of the drinking water requirements of lot fed cattle under Australian conditions.

Within this report, water consumption is ‘free water’ drunk by cattle while water intake includes both water drunk by cattle and water contained in feed. This is discussed further in Section 5.

Water is the most essential nutrient for life. It is necessary for most normal body functions. Provision of ample high quality water is absolutely essential for optimum performance of lot fed cattle. Poor quality water may cause sickness and sometimes death. A system must therefore be designed that allows both adequate trough space and water flow rate to meet the drinking water requirements of cattle.

2.1 Project Reporting Structure

This project includes the collection and analysis of a large quantity of data from operational feedlots on the environmental costs associated with the production of one kilogram of hot standard carcass weight gain (HSCW). In this context, HSCW gain is the difference between total dressed carcass weight of cattle leaving the feedlot less the estimated total dressed carcass weight of cattle entering the feedlot. To ensure all this data and information is presented in a suitable manner, six reports will be compiled.

A. Water Usage at Australian Feedlots. This report presents a background literature review of water usage at feedlots, data collection and results, as well as an analysis and discussion of the data collected. This report is the life cycle inventory for the water use component of the feedlot sub-system.

B. Energy Usage and Greenhouse Gas Emission Estimation at Australian Feedlots. This report presents a background literature review of energy usage and greenhouse gas emissions at feedlots, data collection and results. A discussion of results and the relative merits of the current greenhouse gas emission calculation methodology by the Australian Greenhouse Office are included. This report is the life cycle inventory for the energy use and greenhouse gas emissions component of the feedlot sub-system.

C. Nutrient Cycling at Australian Feedlots. This report includes a literature review of nutrient pathways at feedlots, data collection and results as well as an analysis and discussion of the data collected. This report is the life cycle inventory for the nutrient cycling component of the feedlot sub-system.

D. NPI Listed Substances Emission Estimation for Australian Feedlots. This report provides a summary of the National Pollutant Inventory (NPI) reporting framework, data collection and results for category I listed substances. The report also includes a discussion of the relative merits of the current NPI emission estimation methodology, with guidance on an alternative method for use under Australian conditions.

E. Review of Lot Fed Cattle Water Consumption – MRC Project No. DAQ.079. This report provides a review of research undertaken in the early 1990’s on water consumption in feedlots. It provides a more detailed literature review on the factors influencing drinking water requirements than is provided in Part A, experimental methodology, data collected and discussion of the results and outcomes of this MRC research.

F. Resource Use and Environmental Impact Assessment for Australian Feedlots. This report provides a summary of feedlot-relevant natural resources management issues, data collection and results. A discussion of the environmental impact of the use of these resources by beef cattle feedlots is also included.

3 Life Cycle Assessment

Meat and Livestock Australia is undertaking a project (COMP.094) that will provide credible data on the red meat industry's environmental impacts and sustainability for use by industry, including its interactions with government, community groups and the media. This project will utilise the standardised tool, Life Cycle Analysis (LCA), to quantify natural resource consumption and environmental interventions to water, soil and air. This project (FLOT.328) is being undertaken for the lot feeding sector of the Australian red meat industry. The following description of LCA is taken from Peters et al. (2005).

3.1 Description of Life Cycle Assessment

LCA is a form of cradle-to-grave systems analysis developed for use in manufacturing and processing industries to assess the environmental impacts of products, processes and activities by quantifying their environmental effects throughout the entire life cycle. LCA can be used to compare alternative products, processes or services; compare alternative life cycles for a product or service; and identify those parts of the life cycle where the greatest improvements can be made. An international standard has now been developed to specify the general framework, principles and requirements for conducting and reporting LCA studies (Standards Australia 1998). LCA differs from other environmental tools (e.g. risk assessment, environmental performance evaluation, environmental auditing, and environmental impact assessment) in a number of significant ways. In LCA, the environmental impact of a product or the function a product is designed to perform is assessed, the data obtained are independent on any ideology and it is much more complex than other environmental tools. As a system analysis, it surpasses the purely local effects of a decision and indicates the overall effects.

There are four aspects of life cycle assessment (Figure 1):

- *Goal and Scope Definition* defines the goal, functional unit and associated system to be studied.
- *Inventory Analysis* analyses all process inputs and outputs. It involves modelling unit processes in the system, considered as inputs from the environment (resources, energy) and outputs (product, emissions, waste) to the environment. Allocation of inputs and outputs needs to be clarified where processes have several functions (for example, one production plant produces several products). In this case, different process inputs and outputs are attributed to different goods and services produced. An extra simplification used by LCA is that processes are generally described without regard to their specific location and time of operation.
- *Impact Assessment* makes results from the inventory analysis more manageable and understandable in relation to natural environment, human health and resource availability.
- *Interpretation* involves evaluating inventory analysis and impact assessment outcomes against the study's goal.

An LCA is essentially a quantitative study. Sometimes environmental impacts cannot be quantified due to a lack of data or inadequate impact assessment models. Quantitative analysis requires standardised databases of main processes (energy, transport) and software for managing the study's complexity.

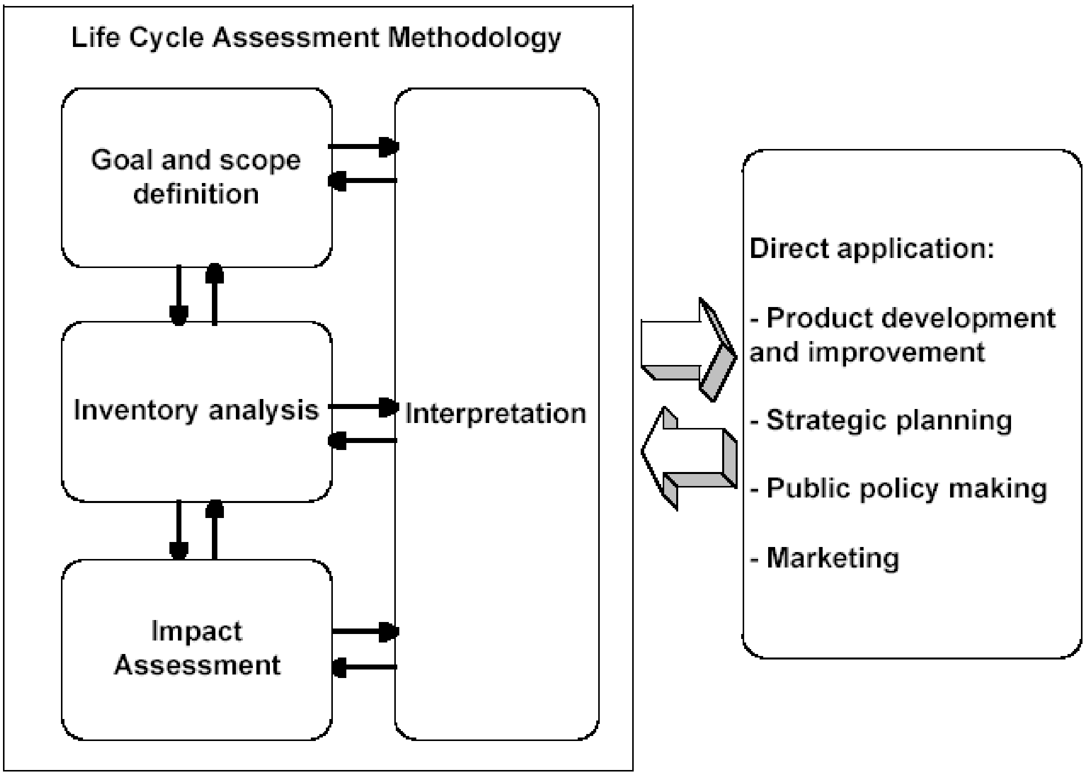


FIGURE 1 - GENERAL FRAMEWORK FOR LCA AND ITS APPLICATION (STANDARDS AUSTRALIA 1998)

3.2 Selection of Functional Unit

The functional unit for this study is the delivery of one kilogram of hot standard carcass weight (HSCW) meat at the abattoir. AUS-MEAT is the authority for uniform specifications for meat and livestock in Australia. In March 1987, they introduced the term HSCW as a national standard. The HSCW is the fundamental unit of "over the hooks" selling and is the weight, within two hours of slaughter, of a carcass with standard trim (all fats out). This is a carcass after bleeding, skinning, removal of all internal organs, minimum trimming and removal of head, feet, tail and other items (AUS-MEAT 2001). "Hot" indicates that the meat in question has not entered any chilling operations. This output-related functional unit was chosen, rather than an input-related one, in order to describe the human utility of the processes under consideration – the provision of nutrition for people. Although the meat could be served in different ways, this functional unit makes the different processes under consideration "functionally equivalent" from a dietary perspective.

3.3 System Boundaries

In LCA methodology, usually all inputs and outputs from the system are based on the ‘cradle-to-grave’ approach. This means that inputs into the system should be flows from the environment, without any transformation from humans. Outputs should also be discarded to the environment without subsequent human transformation (Standards Australia 1998). Each system considers upstream processes with regard to the extraction of raw materials and the manufacturing of products being used in the system and it considers downstream processes as well as all final emissions to the environment.

Figure 2 shows the generalised system boundary for the red-meat sector as defined for the COMP.094 project. Within this boundary, there is a sub-system for the feedlot sector. The boundary chosen here (shown in red on Figure 2) is the feedlot site itself, plus the transport component of bringing cattle and feed into the feedlot and delivering cattle from the feedlot. The production of feed for the feedlot will be examined in a larger system analysis.

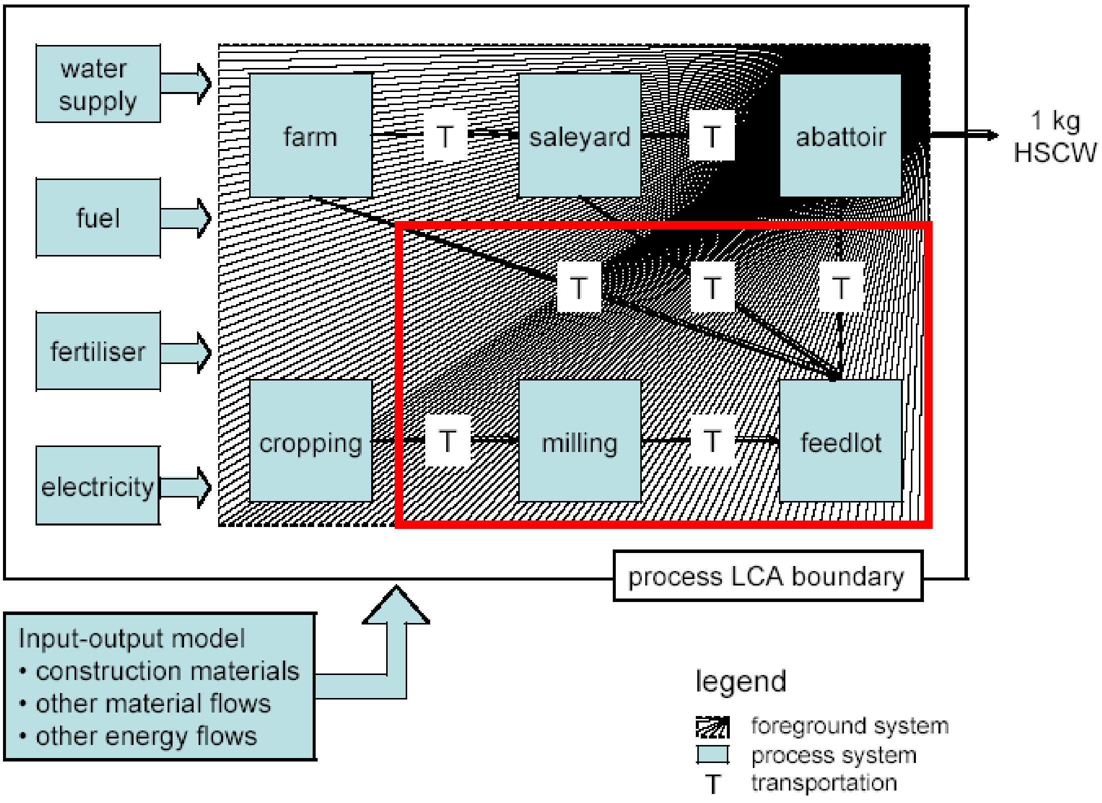


FIGURE 2 - GENERALISED SYSTEM MODEL FOR THE RED MEAT SECTOR WITH FEEDLOT SUB-SYSTEM

3.4 Life Cycle Inventory

Inventory analysis is the second phase in a life cycle assessment and is concerned with data collection and calculation procedures. The Inventory Analysis phase forms the body of the LCA, as the majority of time and effort in an LCA is spent on Inventory Analysis. As a rule of thumb, 80 percent of the time required for an LCA is needed for this phase. The operational steps in preparing a life cycle inventory (LCI) are according to ISO 14041 (Standards Australia 1999):

- Data collection.
- Relating data to unit processes and/or functional unit.
- Data aggregation.
- Refining the system boundaries.

4 Review of Lot Fed Cattle Water Consumption Sub Project - MRC Project DAQ-079

4.1 Introduction

The Meat Research Corporation (MRC) funded a program of research in the early 1990's aimed at addressing the following objectives:

- To obtain a consistent and repeatable industry standard for the measurement of feedlot odours.
- To identify the characteristics of rainfall runoff from feedlot surfaces.
- To identify and quantify the rate of dispersion of odours from feedlot operations.
- To conduct and report on community 'annoyance' surveys of odour dispersion from feedlots.

The methodology of the MRC DAQ.079 project included:

- Odour measurement.

Extensive odour generation measurements to identify the frequency, intensity, duration and offensiveness of feedlot odours were undertaken. Factors influencing odour generation in feedlots were identified and the effect of these quantified.

- Hydrology Research.

Surface hydrological studies using the established research sites were undertaken. Data collected was used to formulate designs suitable to the sub-tropical Australian environment. Cattle drinking water usage was monitored to substantiate the hydrologic and odour generation models.

- Extension

The research team organised workshops for consultants in Queensland and New South Wales to improve their knowledge of feedlot odour, hydrology and appropriate design of management practices to control air and water pollution. Environmental assessment of feedlots and the writing of acceptable environmental impact studies relating to feedlots were also discussed.

4.2 Water Consumption Project

As a subset of the hydrology research, cattle drinking water usage data was monitored. Heat stress of cattle is a concern in Australian commercial feedlots during the summer months. From December to February heavily finished *Bos taurus* cattle, with thick, dark coloured coats, fed a high salt, high protein diet are most affected.

Cattle suffering thermal stress dissipate unwanted heat from the body using evaporative cooling methods. Additional water is needed for this cooling process which comes from body stores. Water therefore needs to be replenished if the animal's water balance is to be restored to equilibrium levels.

Various management options are available to assist animals in maintaining their heat balance in a hot environment. The provision of shade and adequate water are two strategies that are successfully used in feedlots today. Shading is used to block radiant heat reaching the cattle whilst water is used by the animal for evaporative cooling. Fans, sprinklers and dietary manipulations are also sometimes used in feedlots to help alleviate the level of stress cattle may experience.

The very limited information available on the diurnal water consumption pattern of feedlot cattle is based on American studies or work done in constant temperature chambers. Up until the DAQ.079 project was undertaken, there was no data concerning the drinking trends of lot fed cattle exposed to Australian environmental conditions.

This project investigated the water consumption of lot fed cattle under Australian conditions. The patterns in water consumption throughout the day, including peak water consumption as affected by environmental parameters, feed time and composition, diet moisture content, water temperatures and shade were determined. This information can be used to better design watering systems in feedlots. Respiration rate, a measure of heat stress, was also used to establish if there was a correlation between water consumption and respiration rate. A high respiration rate might indicate that cattle drink more water, therefore being a helpful sign to feedlot managers.

The objectives of this subset of the Feedlot Hydrology component of the DAQ-079 project were:

- To measure the diurnal water consumption trend per hour and the daily water consumption of cattle in feedlots under hot environmental conditions with and without shade provision.
- To determine whether shade significantly influences water consumption, behavioural patterns and liveweight of cattle.
- To determine which variables (in particular environmental variables) most significantly influence water consumption and to what extent.

4.3 Reason for this Review

Water usage is an integral component of the life cycle inventory for the feedlot subsystem. A major component of water usage at feedlots is cattle drinking water. Little information is available on the drinking water requirements for lot fed cattle under Australian conditions. There is little information on peak consumption, annual consumption or any knowledge of storage requirements to provide minimum supply rates (Tucker et al. 1991). It's of particular importance to know how much water an animal requires in areas with limited access to water, during drought conditions and during heat waves.

This report reviews the original research to provide a better understanding of water consumption requirements of livestock for the feedlot subsystem, thereby enhancing the life cycle inventory.

5 Literature Review

Lyndon (1994) undertook a comprehensive review of literature available at the time on the factors influencing water consumption. This report incorporates a substantial component of Lyndon's review along with a review of more recent research on water consumption. Therefore specific credit to Lyndon (1994) is acknowledged.

Within this literature review, the definitions of water consumption ('free water' drunk by cattle) and water intake ('free water' drunk by cattle plus feed water) have been applied consistently as much as possible. However, some previous reports related to cattle drinking water do not clearly define water consumption or water intake and appear to use the two terms interchangeably. Three previous reports are particularly relevant to this review:

- Winchester and Morris (1956), who used the definitions discussed above – water intake was the key parameter studied.
- Hicks et al. (1988), who did not define the terminology used.
- Sanders et al. (1994), who did not specify the terminology used – inspection of data available from their work suggests that water consumption was the key parameter studied.

The key outcome of this report is a review of the Sanders et al. (1994) work, thus water consumption is the key parameter considered.

5.1 Introduction

Water is the most vital single requirement of livestock as they are dependent on it for survival. Water is an extremely important nutrient since it makes up about two thirds of the fat-free animal's body (Church 1979). It contains dissolved crystalloids or is bound to colloids within the body. It is part of the colloidal proteins and therefore is an essential component of living cells. Water is chemically inert but is involved in many biochemical reactions. All polymerizations and deploymerizations use or release water. Water is essential for electrolyte metabolism and function (Church 1979).

The water consumption of feedlot cattle increases dramatically during hot periods. Water helps to offset the negative effects of metabolic heat during periods of hot weather. It is required to prevent dehydration, but many animals will drink and use extra water just to cool the body by placing the tongue and nose in the water to dissipate body heat (Sparke et al. 2001).

Water is important for:

- The elimination of wastes from digestion and metabolism (i.e. faeces and urine).
- The regulation of the blood osmotic pressure.
- Thermoregulation. As cattle are homeotherns, they have the ability to maintain their body temperature within a narrow range, irrespective of environmental fluctuations.
- Optimising performance. An ample supply of good quality water is necessary for optimal performance.

The water requirements of livestock are met by three different sources:

- Water consumed voluntarily (i.e. water that is drunk).
- Water consumed in feed.
- Water obtained within the body due to oxidation reactions involved in metabolism formed within the body as a result of oxidation in the tissues.

Water intake is the sum of water consumed voluntarily and water consumed as part of feed. It is regulated by the hypothalamus. If the temperature-regulating centre in the anterior hypothalamus is warmed (e.g. in a hot environment), the animal will consume more water than usual (McDowell 1972 cited in Lyndon 1994).

Water is constantly being expelled from the animal's body through secretory products, wastes, exhalation and sweat. A minimal water loss of 2-5% of the total body water is vital to the animal as it ensures the continuation of the respiratory process and the excretion of metabolic products through urine and faeces. Figure 3 is a conceptual illustration of the water balance of a 450 kg feedlot steer from Watts, Tucker and Casey (1994).

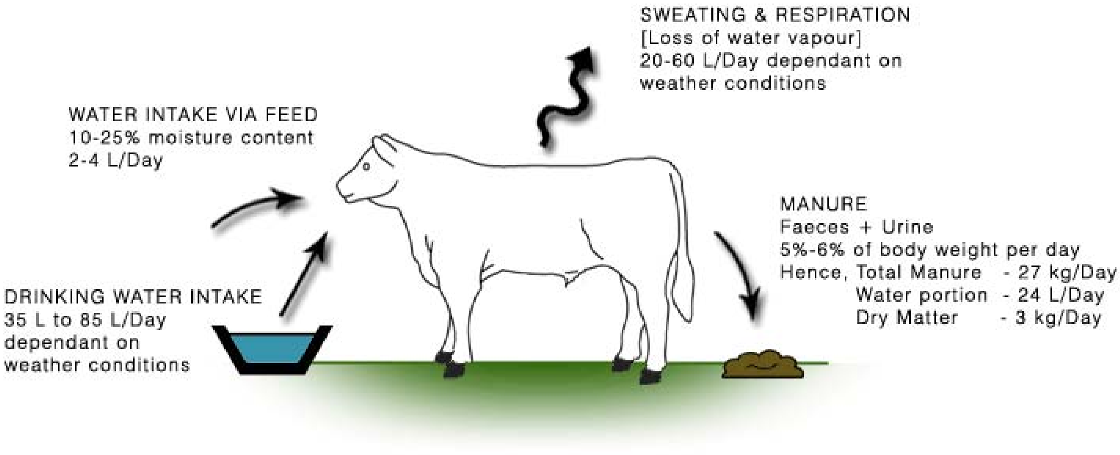


FIGURE 3 - CONCEPTUAL WATER BALANCE OF 450KG FEEDLOT STEER (WATTS, TUCKER & CASEY 1994)

5.2 Factors Influencing Water Consumption

The quantity of water consumed by feedlot cattle is mostly dependent on the environmental temperature and humidity, drinking water temperature, ration composition (nature of food and dry matter content), feed intake, size of the animal, rate and composition of gain, frequency of watering and individual variation between animals (ARC 1980).

5.2.1 Environmental Factors

The animal's environment directly influences its drinking pattern, performance and even survival. Weather is usually considered a constraint on efficient livestock management as it is unpredictable and variable. Livestock water requirements may be influenced by the following meteorological parameters: ambient temperature, relative humidity, wind speed, solar radiation and rain (Hicks et al. 1988).

Each of these factors influences the animal's final physiological state, thus determining the volume of water consumed by the animal. It is important to consider each of these factors individually. Conditions of high humidity, wind and rainfall all tend to decrease the voluntary consumption of water (ARC, 1980).

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). Most of this research has examined the effects of shade, diet modification, microclimate and development of an index for heat stress.

Ambient temperature is a measure of the intensity of heat. Cattle exposed to high ambient temperatures will inevitably become hot and need to cool themselves. Ray (1991) regards temperatures exceeding 21°C as stressful. Increasing water consumption is an important method of reducing body temperature due to its involvement in the evaporative cooling process. High temperatures limit the animal's ability to dissipate heat by radiation, conduction and convection and therefore they are solely dependent on the evaporative pathway (Lyndon 1994). High ambient temperatures tend to increase the consumption of water (ARC 1980). Little et al. (cited in ARC 1980) found voluntary feed intake declined when water consumption was restricted.

In temperate climates, water is required mainly to meet physiological needs. Species vary in their ability to tolerate dehydration and in their ability to use water to maintain a state of homeothermy (ARC 1980). Cattle seem to reduce the output of water in faeces in response to water restriction. They do not appear to restrict output of water in urine significantly (Little et al. cited in ARC 1980).

Relative humidity is defined as the ratio of the quantity of water vapour present in the air relative to the amount of water in saturated air. The potential for evaporative heat loss is influenced by the difference between the water vapour pressure at the skin surface temperature and the actual vapour pressure of the ambient air. As the humidity of the air increases, the ability to lose heat by evaporation is reduced, becoming zero at a relative humidity of 100%. Evaporation is possible in saturated air, providing the membrane of the respiratory passage has a higher temperature and therefore a higher saturation vapour pressure than the surrounding air.

Increasing humidity associated with high temperatures reduces total water intake but cattle drink more frequently (Ragsdale et al. 1953 cited in ARC 1980). This may be partly due to the lower feed intake and the reduced vaporization of water (ARC 1980).

Radiation from the sun, sky and surroundings contribute to the animal's heat load. An unshaded beast is exposed to:

- Direct solar radiation (visible and short infrared waves) from the sun. A proportion of this radiation is reflected by the coat and the remainder is absorbed.
- Solar radiation reflected from the clouds and other particles in the sky.

- Solar radiation reflected from the ground and other surrounding objects (amounting to approximately 50% of the total solar radiation).

The amount of heat an animal absorbs from solar radiation is influenced by the intensity of the radiation, the animal's orientation to the sun and the absorptive reflective capacity of the animal's coat. McArthur (1987) found that radiation is directly responsible for increased skin temperature which stimulates the secretion from the sweat glands. There are particular situations where wind can influence the heat transfer between an animal and its environment.

Rapid air movement will enhance evaporative heat loss only when the skin is moist and where air temperature is below that of skin temperature. Wind may also have a heating effect if air temperature is above surface temperature and its effectiveness in heat exchange will be limited if the skin moisture supply is low. Wind of 4.5 m/s at temperatures of 10-26.7^{o}C has been found to reduce the water intake of European cattle slightly. At 35^{o} degrees wind velocity did not seem to have an effect with wind speeds of 1.8 m/s and 4.5 m/s (Brody et al. 1954 cited in ARC 1980).

Rain reduces water intake due to the associated heat loss through evaporation. Rain falls onto the animal's coat and evaporates, reducing thermal stress. The cooling effect is directly related to the depth of water penetration into the coat. Castle et al. 1972b (cited in ARC 1980) found that rainfall decreased the water intake requirements due most likely to reduced vaporisation.

Donegan, Clarke and Sivasupraunaniam (1984) proved that high humidity, poor air movement and high solar radiation all interfere with the animal's ability to dissipate heat. They concluded however that the primary cause of heat stress is high air temperatures.

There have been several approaches to estimate the combined thermal effects of components of the physical environment on man and animals. These approaches have utilised various heat transfer components to obtain estimates of the net effect of the thermal environment on the heat balance of the animal (Sparke et al. 2001).

Instrumentation that combines the effects of two or more meteorological measures to give an estimate of a potential thermal effect on an animal has been developed and includes Black Globe Temperature (BGT) and Thermal Load Monitor (TLM) and Kata Thermometer (Sparke et al. 2001).

There has been considerable scientific effort directed towards developing mathematical indices representing the physical environment (air temperature, humidity, radiation, wind speed) in terms of one or more measurable physiological or animal production response.

Bonsen (1959) and Kibler (1964) found that ambient temperature and relative humidity are the two most important environmental factors influencing heat stress. They came up with a Temperature-Humidity Index, (THI), to express them in combination. This index is beneficial in relating these parameters to physiological comfort.

THI is an empirically determined index weighting dry bulb and wet bulb or dew point temperatures for comparison with animal performance. This index arose from an earlier "Discomfort Index" for humans (Thom 1959). Kibler (1964) adapted Thom's measurements to develop the THI for evaluating the combined effects of air temperature and humidity on the DMI and milk yield of dairy cows.

While the THI is widely used in livestock industries, its origin is from research on dairy cows to estimate the effect of hot and humid environments on milk production, and, as yet, has not been fully evaluated for use with feedlot cattle with regard to beef production or animal survival. Various weightings for the temperature and humidly values are reported in the literature (Findlay 1958; NAS 1971; Baeta 1985; Hahn 1994; Hahn & Mader 1997 cited in Sparke et al. 2001).

Research from the University of Missouri (Johnson et al. 1963; Kibler 1964; Hahn & McQuigg 1976 cited in Sparke et al. 2001) showed that reductions in the milk yield of dairy cattle related to increasing THI. Lactating cows had little discomfort at THI <70, but feed intake and milk yield were depressed at THI >75. Cattle of most types showed measurable discomfort at THI >78 and discomfort became more severe as THI values further increased.

Wet Globe Temperature Index (WGTI) (Lee, 1980; ASHRAE, 1993 cited in Sparke et al. 2001) combines Wet Bulb with Black Globe Temperatures to effectively account for long-wave infra-red radiant heat transfer and dry bulb temperature. Black Globe Humidity Index (BGHI) was developed (Buffington et al. 1981 cited in Sparke et al. 2001) substituting the Black Globe Temperature for Dry Bulb Temperature in the THI formula, in an attempt to integrate dry bulb temperature, relative humidity, net radiation and wind movement into a single value.

Gaughan et al. (2001) concluded that high heat load in feedlot cattle is a result of local climatic conditions (i.e. in the pen) and animal factors leading to an increase in body heat beyond the animals' normal physiological range and its ability to cope. By using a combination of observed local climatic conditions and animal responses to the climate (e.g. panting scores) feedlot management is well placed to implement strategies to reduce the impact of severe hot weather conditions on their cattle. Gaughan et al. (2004) found that Black globe temperature should be used instead of ambient temperature and proposed a heat load index (HLI) defined for when BGHI exceeds 79, and when BGHI is less then 79. Quintarelli (2004) developed a weather forecasting system to assist in warning feedlot operators of impending adverse weather conditions that could lead to excessive heat loads (and potential mortality) for feedlot cattle. Forecasts were posted daily onto a website (www.katestone.com.au/mla) for easy access to all feedlot operators. Quintarelli (2004) found good agreement between the forecast heat load index (HLI) and the observed HLI out to 3 days ahead (60 to 80%), with reduced strength in the relationship out to 6 days ahead (20 to 60%).

5.2.2 Breed of Cattle and Heat Stress

Studies undertaken by Winchester and Morris (1956) indicate a definite breed difference in water consumption patterns. They provide data relating water intake per day to ambient temperature, dry matter intake and breed. These data (converted to metric units) are given in Figure 4. Their studies indicate that *Bos indicus* cattle drink significantly less than the *Bos taurus* breeds (Figure 4).

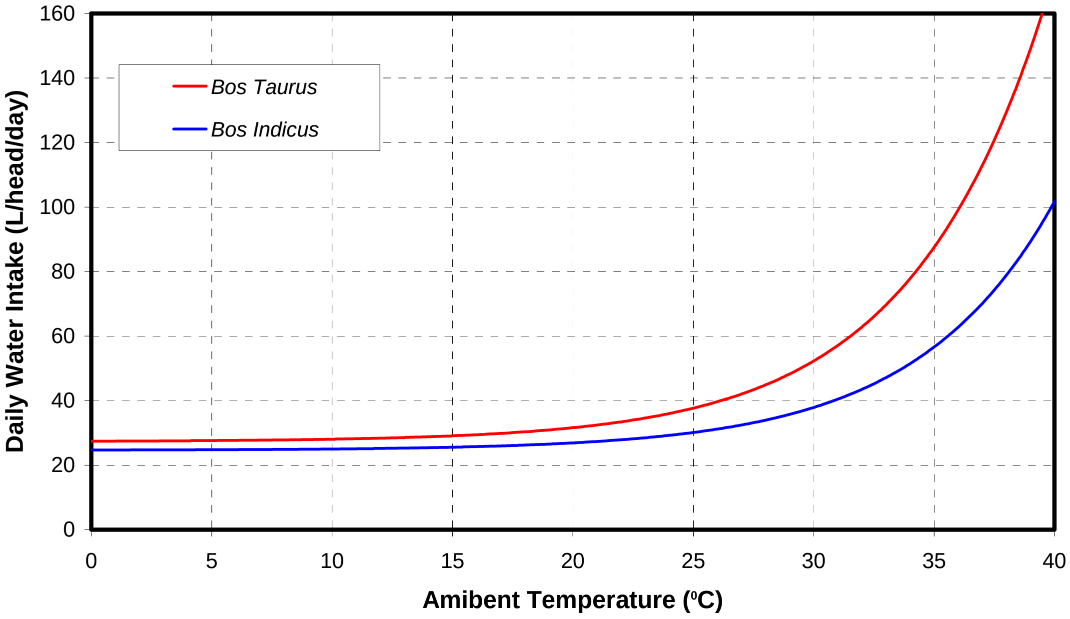


FIGURE 4 - WATER INTAKE EXPRESSED AS A FUNCTION OF DRY MATTER INTAKE (11 KG DMI PER DAY) AND AMBIENT TEMPERATURE. (CURVES ARE ADAPTED FROM WINCHESTER AND MORRIS 1956).

These breed differences in water intake are not fully understood. However, *Bos indicus* cattle have an adaptive advantage in hot environments compared to the European and British breeds. They are better able to maintain body temperature in hot conditions. This may explain the significant water intake differences.

Bos indicus cattle have a greater surface area to weight ratio than the *Bos taurus* breeds (Blackshaw & Blackshaw 1991). From these results, it would be reasonable to assume that a greater surface area would provide a greater area from which heat may be dissipated. Robinson and Klemn (1953) (cited in Lyndon, 1994) showed that the *Bos indicus* breeds have a greater tissue conductance capacity, therefore enabling a quick heat transfer from the body core to the skin.

Results recorded on the sweating capacity of different breeds showed that *Bos indicus* breeds have a definite sweating advantage over the *Bos taurus* cattle. Ferguson and Dawling (1953) cited in Lyndon (1994) found *Bos indicus* cattle have a higher density of sweat glands than the European breeds.

Allen (1961) (cited in Lyndon 1994) found that when British cattle were subjected to mild environmental conditions they had a higher sweating rate than the *Bos indicus* cattle (*Bos indicus* didn't start sweating until air temperature exceeded 30°C). Under more extreme conditions however, the *Bos indicus* cattle had a greater sweating rate relative to the *Bos taurus*.

Bos indicus cattle have a haematological advantage for adapting to heat stress compared with the *Bos taurus* as they are equipped with a higher red blood cell count as well as a higher cell volume.

These haematological values result in a lower respiration rate (Beaver et al. cited in Lyndon 1994). This means that cattle are less heat stressed and will therefore require less water for cooling purposes.

Bos indicus cattle have a lower thyroid activity than the *Bos taurus* breeds when suffering thermal stress. A reduced thyroid activity suggests a lower basal metabolic rate, allowing *Bos indicus* cattle to tolerate elevated environmental temperatures (Beaver et al. 1989 cited in Lyndon 1994).

Worstell and Brody (1953) and Bianca (1959) cited in Lyndon (1994), attributed the low heat tolerance of *Bos taurus* breeds to their inefficient cooling mechanisms, poor sweating rate and their thick coat which hamper the evaporation of sweat.

5.2.3 Diet Composition and Feed Intake

The ingestion of feed leads to an increase in heat production (i.e. heat increment). The calorigenic effect of feed ranges between 35% and 70% of ME, depending on the class of nutrients consumed. Fat has the lowest heat increment, followed by carbohydrates while proteins have the highest calorigenic value (Blackshaw & Blackshaw 1991). The dry matter content and the nature of feed both influence water consumption requirements (ARC 1980). Generally, increased levels of feed intake are associated with increased voluntary consumption of water. Water intake per unit of dry matter intake is greater for low dry matter intakes than for high dry matter intakes (Leitch and Thompson 1944 cited in ARC 1980). When feeds with high moisture content are offered, less water needs to be supplied as drinking water (Luke 1987).

Diets consisting of grain, hay and similar 'dry feeds', which are only about 10% moisture, have a high dry matter content and contribute insignificantly to the total water intake. However the provision of wetter feeds, such as silage-based diets, may provide enough water to significantly reduce the drinking water requirement. Diets with high levels of protein, pentosans, diuretic compounds, crude fibre or salt will all increase the water intake requirement (ARC 1980 cited in Olsen & Fox 1994).

Garza, Owens and Welty (1989) found in their study that beef heifers consumed higher volumes of water when fed concentrate-based diets rather than hay based diets (Figure 5).

In cattle, the microbial population in the rumen contributes additional heat, amounting to up to 10% of the animal’s basal heat production. Houpt (1968) (cited in Lyndon 1994) showed that the heat production of a ruminant immediately following feeding was 15 times greater than at the lowest rate at the end of a 24-hour fasting period.

Salts in the diet will also increase the animal’s water demand as it is a diuretic substance.

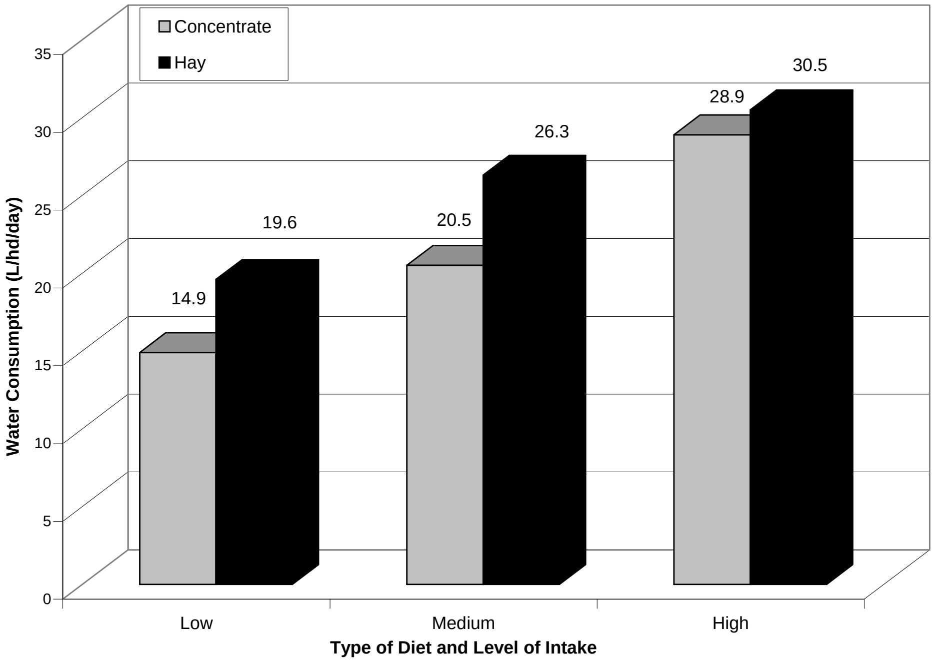


FIGURE 5 - DAILY WATER CONSUMPTION IN BEEF HEIFERS FED CONCENTRATE VS. HAY DIETS. (GARZA, OWENS & WELTY 1989)

5.2.4 Body Size

Water intake is usually expressed as litres per day or as litres/body weight/day (Luke 1987). Growing animals require a greater intake and a better quality of water than animals which have finished growing and are being fattened (Gill 1984).

Heavily finished cattle require additional water relative to leaner beasts. This is because they have a thicker subcutaneous fat layer which acts as an insulating sheet, trapping heat inside the animal (McDowell 1972 cited in Lyndon 1994). Fatter or larger sized animals will also have a reduced surface area to weight ratio (i.e. less surface area from which to dissipate heat), therefore having a greater water requirement than leaner or smaller cattle (McDowell 1972 cited in Lyndon 1994). Animals being fattened also have a lower relative water content in the body (Georgievski, Annenkov & Samokhin 1982).

5.2.5 Coat Characteristics

Coat colour has an important affect on the absorption of solar radiation. Riemerschmid and Elder (1945) (cited in Lyndon 1994) showed that white coats absorb 49% of incident solar radiation, red coats absorb 78%, brown coats 80% and black coats 89%.

The amount of solar radiation absorbed by brown hides contributes three times as much heat as that produced by metabolism. They also found the direction of the hair, smoothness of the coat and the degree of curliness to be of secondary importance.

The depth of the coat largely determines the insulation, with short glossy coats being one resistance strategy for coping with heat stress. Yeats (1955) (cited in Lyndon 1994) showed that clipping coats reduces skin and rectal temperatures, respiration rate and distress under heat wave conditions. Schleger and Bean (1971) cited in Lyndon 1994 also found a positive relationship between sleek coats and a higher sweating rate compared with rough coats. Sleek coats have more active hair follicles, with sweat glands that secrete more efficiently than those associated with woolly coats.

Hair density is also important in heat transfer. Blaxter and Wainman (1964) (cited in Lyndon 1994) found that cattle with a thick coat were at risk of developing hyperthermia at 40.5^0C. Finch et al. (1984) showed that animals with dense dark coats were more susceptible to heat stress in the summer.

5.2.6 Water Quality

The quality of water provided is important for the health and productivity of cattle. If drinking water is poor quality, water consumption can be reduced and subsequently feed consumption will decline. This can result in sickness even death. Water may be unsafe for consumption if it is very saline, contains high nitrate levels, is highly alkaline (this is rarely a problem) or if other factors make it unsafe for drinking (Olsen & Fox 1989).

The most common water quality problem affecting consumption the presence of concentrated minerals i.e. excess salts in the water. Salinity of natural water consists of numerous salts existing in the water as ions. Magnesium, sulphate, chloride, bicarbonate, carbonate, calcium and sodium are the main ions present. The total dissolved salts (TDS) is a measure of the total water salinity. Table 1 provides an indication of tolerance of cattle to salt in drinking water.

TABLE 1 - TOLERANCE OF CATTLE TO SALT IN DRINKING WATER (REPRODUCED FROM WATTS, TUCKER & CASEY 1994)

Salt concentration, mg/L	Drinking Quality
0-1000	good quality - no problems
1000-2999	satisfactory but may cause temporary diarrhoea in unaccustomed stock but won't restrict performance the long term
3000-4999	satisfactory but can cause serious potential problems in unaccustomed stock
5000 +	can cause potential problems

Salts frequently found in stock water include sodium-chloride, calcium-bicarbonates, magnesium-bicarbonate and chlorides and sulphides (Anon, 1988).

Salinity becomes a problem when it results in osmotic effects within the body. Different salts have slightly different effects. However, the effects of all salts seem to be additive. Initially saline water will cause an increased water requirement and therefore an increased consumption of water. Very salty water may cause reluctance to drink. Gastro-intestinal disorders and wasting disease are illnesses associated with excess salt consumption. When salts are present in water at high concentrations, the animal may initially refuse to drink for many days, followed by a period where it drinks large amounts within minutes. This can have harmful osmotic effect, leading to reduced performance, illness, diarrhoea or sometimes death.

Animals will adapt to saline drinking water but only if they are gradually introduced to it (Olsen & Fox 1989).

5.2.7 Frequency of Watering and Water Consumption

Housed cattle and those receiving supplementary feeding tend to drink more frequently than grazing animals (unsupplemented) (Tucker 1991). Cattle maintained under similar environmental conditions and receiving similar diets vary considerably in the amount of water they consume (ARC, 1980). Winchester and Morris (1956) also found that there is also a high degree of variability within individual animals when comparing intake between days during which apparently identical conditions prevail.

Hahn et al. (1999) concluded that there needs to be at least two water troughs per pen with provision for a minimum of linear 25 mm/head of waterer space for normal conditions and 75 mm/head for very hot episodes. Increasing linear waterer space and providing multiple waterers can reduce the influence of dominant animals during hot weather, permitting increased access for the more submissive pen members (EA Systems Pty Ltd, 2003).

5.3 Diurnal Variation in Water Consumption and Its Effect on Water Supply Needs

It is desirable to provide ample water for cattle to access throughout all times of the day. To achieve this, it is not sufficient to consider the total annual drinking water requirement alone, or even the daily requirement as diurnal variations exist in cattle drinking patterns.

A study undertaken by Johnson et al. (1964) (cited in Lyndon 1994) considered the diurnal trends in both water consumption and frequency of drinking with respect to temperature fluctuations. The results indicated that more water was consumed during the day and at more frequent intervals than at night, irrespective of rearing conditions and temperature. They also found that as temperature rose from 0° to 40°C, water consumption for all breeds increased by only two to three times during the day, whereas night consumption rose six to seven fold.

Watts, Tucker and Casey (1994) have also studied diurnal water consumption patterns, but not during heat wave conditions. Their findings were supportive of Johnson's work, stressing that cattle consume most of their water during the day. They recognised a definite water consumption trend over a 24 hour time period, noting that water consumption is suppressed to insignificant levels between 11 pm and sunrise. The period where water deprivation is most likely to occur is from around 9 am to 8 pm, where water consumption requirements peak. They also found water consumption fell for about half an hour after feed delivery. Since water consumption peaks somewhere between 9am and 8pm, it is necessary to design water systems to match peak consumption demands at these times (Figure 6).

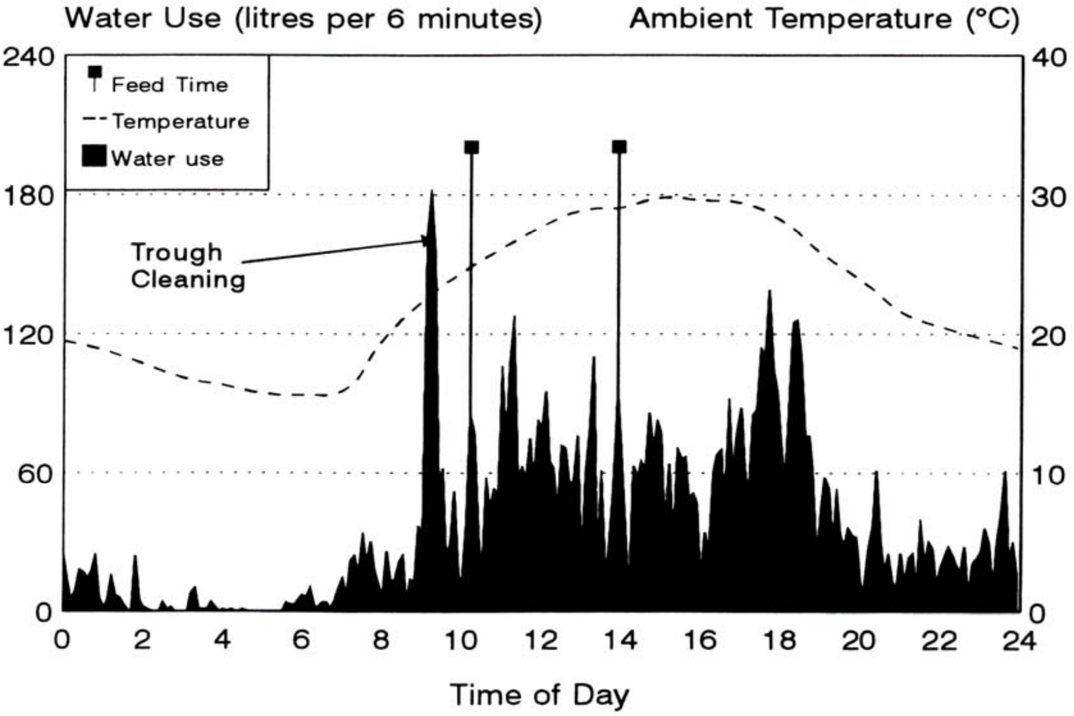


FIGURE 6 - DIURNAL VARIATION IN WATER CONSUMPTION IN FEEDLOTS. (REPRODUCED FROM WATTS, TUCKER & CASEY 1994).

5.4 Physiological and Behavioural Responses to Heat Stress and their Effects on Water Consumption

When an animal is exposed to a hot environment, it will react initially by physiological and/or behavioural changes in an attempt to alleviate its thermal load. An animal is said to suffer heat stress when their ability to dissipate heat or lose it by other means is limited. In most cases, heat stress is precipitated when the gross heat load exceeds the physiological abilities of the animal to metabolically or behaviourally lose heat (EA Systems Pty Ltd 2002).

According to McDowell (1972) (cited in Lyndon 1994), the compensations adopted by animals in an attempt to alleviate excessive heat occur in the following order:

- changes in vascular blood flow.
- initiation of sweating.
- increased respiration rate.

- changes in hormone secretion or endocrine activity.
- changes in behavioural patterns.
- increased water consumption.
- elevation of body temperatures.
- changes in the use of body water.
- changes in the state of hydration.

The compensations of the animal which were of interest in the study by Sanders et al. 1994 were changes in behavioural patterns and water consumption.

5.4.1 Behavioural Changes

McDowell (cited in Lyndon 1994) defines behavioural changes to reduce heat stress as "a shift in the usual pattern, movement and food intake made by the animal to reduce heat production, promote heat loss and/or to avoid adding heat".

Symptoms displayed during exposure to mild heat may include:

- Shade seeking behaviour.
- Orientation to the sun, if no shade is available.
- Reduced roughage consumption in relation to concentrates.
- Refusal to lie down (an attempt to maximise surface area).
- Huddling or grouping behaviour, aimed at seeking shade from other animals.
- Body splashing.
- Crowding around water troughs for cooling purposes, not just to drink (Blackshaw & Blackshaw 1991).
- Adopting a relaxed position to minimise exertion e.g. ceasing to graze.

Signs of advanced thermal stress may include:

- open mouthed breathing with head extended, tongue protruded and profuse salivation.
- animals becoming restless, dull, lie down more frequently and stumble whilst walking (Lyndon 1994).

5.4.2 Water Consumption

When an animal is heat stressed, additional water is used for evaporation from the body. The direct action of water being drawn from these sources stimulates the 'thirst centre' in the hypothalamus, thus resulting in a positive water uptake as ambient temperature increases (McDowell 1972 cited in Lyndon 1994). Bianca (1963) in his study found that cattle deprived of water were capable of consuming up to 65 litres within a few minutes.

5.5 Management of Thermal Stress and its Effect on Water Consumption

In recent times there has been increased awareness of the issue of thermal stress on feedlot cattle. There are concerns that thermal stress may affect animal production and welfare. Management strategies can be implemented to reduce the thermal stress. These strategies in turn may also influence water consumption. 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, EA System Pty Ltd, 2004). Most of this research has been on the effects of shade, diet modification, microclimate and development of an index for heat stress. However, little work on the effects of heat stress management processes on water consumption has been undertaken.

5.5.1 Shade

The lack of shade in feedlots has been implicated as restricting the ability of cattle to reduce their radiative energy load (Blackshaw & Blackshaw 1994, EA Systems Pty Ltd 2003). In hot climates, shade can be utilised by cattle to provide relief from the ambient temperatures that induce excess body temperatures. Owen cited in EA Systems Pty Ltd (2003) describes the benefits of shade (reduction in heat load) to animals exposed to both high temperatures and high solar radiation with the effectiveness of shade being dependant upon size of shadow, location of shade, shade orientation, and type of shade material.

Daly (1984) observed that cattle intolerant to heat used the shade during the hottest periods. He also observed a general migration trend away from the shade during the cooler times of the day to feed and drink. In situations where cattle do not have access to shade, they pick out watering points as a substitute for cooling. It must be noted however, that access to water is less effective in reducing thermal stress than provision of shade. British bred cattle with access to shade appear to be more content as they chew their cud during the middle of the day, unlike unshaded cattle. Another study conducted by Daly (1984) with shorthorn steers found a positive relationship between shade use and temperature and humidity. As the temperature and humidity rose, so too did the time spent under the shade.

Notwithstanding the perceived need to provide shade in feedlots that are likely to experience extended periods of hot weather conditions, the benefits, both in regard to animal productivity and physiological stress indicators, have not been conclusively established (Esmay, 1978; Curtis, 1983 cited in EA Systems Pty Ltd. 2003; Rinehart & Tucker, 1994; Mader et al. 1999 and Sparke et al. 2001). In addition, the impact of shade on drinking water consumption has not been conclusively established.

5.5.2 Water Temperature

Supplying cool water for drinking has a limited direct cooling effect, but does produce some indirect benefits, including: improvements in feed conversion, reduced illness, improved cooling ability and improved body functions. It also maximises the cattle's natural cooling ability through sweating, breathing and decreasing body temperature (Lofgreen et al. 1975).

There is some evidence that, as water temperature increases, cattle water consumption increases. Research has shown that under controlled conditions, cattle water consumption rises as water temperatures increase up to 27° C. Above 27° C, water consumption is mainly a factor of dry matter intake and temperature (Ragsdale et al. 1950, Winchester and Morris 1956). Lofgreen et al. (1975) found that in a hot environment, provision of cooled drinking water improved the performance of British feedlot cattle.

Hereford cattle in a dry lot were subjected to daily maximum temperatures of 38°C. When water temperature was reduced from 31°C to 18.3°C, water consumption was reduced and daily liveweight gains improved in the order of 277g per animal (Ittner (1951) in Watts, Tucker & Casey (1994)).

EA Systems Pty Ltd (2004) found in a study of cooling lot fed cattle that drinking water should be supplied at around 16-18°C and not above 25°C and that the temperature of the drinking water should be consistent.

5.5.3 Sprinklers

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. There has been little research undertaken in Australia on the effects of cooling stock by wetting as this can lead to negative secondary impacts such as wet pens and increased odour emissions.

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 (EA Systems Pty Ltd 2004).

Sprinklers and misters may be effective during periods of extreme heat when the relative humidity is low. Overuse creates boggy pens and associated odour problems. Judicious use of sprinklers and misters will help to cool the cattle and may also aid in dust control (Rinehart & Tucker 1994). Kelly et al. (1955) showed that sprays and sprinklers had a beneficial result in increasing weight gains.

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 30-35°C 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 (EA Systems Pty Ltd 2004).

5.6 Estimating Water Consumption Requirements

Attempts have been made to establish relationships for predicting daily water requirements of cattle when performing at optimal levels. Lee (1965) identified three basic difficulties which hamper the accuracy of predicting such a formula. These include:

- Unpredictable environmental variables e.g. temperature, humidity, air movement, radiant heat and precipitation.
- Individual variability e.g. metabolic rate, coat, age, sex, acclimatisation, nutrition, hydration and disease.
- Differences in physiological conditions between animals e.g. growth, level of productivity, pathological patterns, stage of reproduction and physiological responses.

It would be impossible to take into consideration the effects of all these variables in a single index. Therefore, when formulating a water consumption index, scientists usually ignore insignificant contributors to water consumption. It must be stressed that when predicting water consumption, it is important to use measurements from a large number of animals due to the wide variation among individual animals and even differences between consumption of a given animal on consecutive days under similar conditions.

Studies by Winchester and Morris (1956) relate water intake per day to ambient temperature, dry matter intake (DMI) and breed. Their trials were conducted in a constant temperature chamber.

Results showed that up to an ambient temperature of 30^{o}C, the rate of water consumption per unit dry matter intake remained fairly constant. As the temperature exceeded this level, consumption rose dramatically due to increased evaporative (cooling) demand. Winchester and Morris (1956) measured actual water intakes of 16 L/kg DM intake per day by *Bos taurus* breeds, and about 10 L/kg DM intake per day for *Bos indicus* breeds.

Watts, Tucker and Casey (1994) developed the following relationships from the collated data of Winchester and Morris:

Bos Taurus - $WI = DMI \times (3.413 + 0.01592\, e^{0.17596T})$ **EQUATION 1**

Bos indicus - $WI = DMI \times (3.076 + 0.008461\, e^{0.17596T})$ **EQUATION 2**

Where:
WI = water intake (litres per head per day)
DMI = dry matter intake (kg DM per head per day)
T = ambient temperature (degrees celsius)

Hicks et al. (1988) devised a different water intake formula, including additional variables (precipitation and salt content) to those used by Winchester and Morris. The trial was conducted during the months of June through to September and involved 239 crossbred steers with an average starting weight of 330 kg. The resulting formula (converted to metric units) is:

$$WI = -6.1 + 0.708 \times T + 2.44 \times DMI - 0.387 \times P - 4.44 \times S \qquad \textbf{Equation 3}$$

Where:

WI = Water intake (L/head/day)
DMI = Dry matter intake (kg DM/head/day)
T = Daily maximum temperature (^{o}C)
P = Precipitation (mm/day)
S = Dietary Salt (%)

NOTE: At average temperatures (< 20°C) and for small cattle (< 450 kg), the formulae of Winchester and Morris (1956) and Hicks et al. (1988) produce similar water intake requirements. As temperatures exceed 35°C however, and cattle sizes increase, results vary. However, Hicks et al. (1998) did not take any measurements under these conditions.

Another trial conducted by Johnson et al. (1958) compared Shorthorn, Santa Gertrudis and Brahman cattle at 10°C and 27°C. At high environmental temperatures, all breeds of cattle consumed almost twice that demanded at the lower temperature. At 10^{o}C, average consumption was 8.4 to 33 L/kg gain and at 27°C, it rose from 12.5 L to 49.9 L/kg gain. For Shorthorn cattle, there was a greater rate of increase in water consumption at 27°C compared to 10°C relative to the other breeds.

An anecdotal, and generally accepted, value for water consumption for a 650 kg animal is 50 litres/day. Hahn et al. (1999) and Mader et al. (1999) suggest all waters should be tested to supply at least 15 litres/100kg of live bodyweight daily during feedlot peak demand periods, and able to meet the daily peak consumption needs in a four-hour demand period.

Little information is available on the water requirements for lot fed cattle under Australian conditions. There is little information on peak consumption, annual consumption or any knowledge of storage requirements to provide minimum supply rates (Tucker et al. 1991). It is particularly important to know how much water an animal requires in areas of limited access to water, drought conditions and heat wave exposure.

There are concerns about this lack of knowledge among the lot feedinq industry, particularly with regard to inadequate water supply to troughs during times of peak water demands. This limitation is most likely to occur during the summer months when heat stress is most common and more water is consumed. There is a need for further information on the relationship between water consumption and environment and for cattle held in Australian conditions.

6 Materials and Methods

6.1 Experimental Sites

From December 1993 to March 1994, water consumption studies on lot fed beef cattle were undertaken at the two feedlots in Southern Queensland. Feedlot A is located 16 km south-west of Condamine on the Western Darling Downs at latitude 27°01' S and longitude 150°00' E. The elevation is 275 m above mean sea level. This feedlot experiences summers with mean maximum temperature of 33°C.

Feedlot B is located approximately 150 km east of Feedlot A and approximately 18 km North-East of Dalby at a latitude of 27°10' S and longitude 151°25' E. The elevation is 390 m above mean sea level. This feedlot experiences summers with a mean maximum temperature reaching 32°C.

FIGURE 7 - LOCATIONS OF FEEDLOT A AND FEEDLOT B IN SOUTHERN QUEENSLAND.

6.2 Duration of Trial

The trial was conducted over the summer of 1993/1994. The treatments at Feedlot A and B commenced on the 1st of November 1993 and were concluded on the 12th of March and 27th April 1994 for Feedlots B and A respectively.

6.3 Experimental Design

The study's experimental design had to be considered in light of both feedlots' commercial operations. The effects of spatial variability were also considered as both feedlots differed in their location, pen layout and management techniques (e.g. feeding times, diet composition, pen design, varying levels of water salinity, climate etc).

It was aimed to keep spatial variability within the two feedlots to a minimum. Hence, pens of the same size and cattle of a similar age and weight were chosen. The experimental design was restricted to an allocation of four pens per feedlot and, although cattle breeds were all of *Bos taurus* origin, there was a fair range in cattle type, due to the commercial operation of both feedlots.

The experiment consisted of two replications of two treatments (shaded vs. unshaded) across two feedlots i.e. two pens at each site were shaded and two were unshaded as shown in Table 2.

6.3.1 Pen Layout

Figure 8 and Figure 9 illustrate the pen layout at Feedlot A and B respectively. Table 2 lists the dimensions and areas of the individual pens at Feedlot A and B used for in the trial.

TABLE 2 - REPRESENTATION OF EXPERIMENTAL DESIGN AND PEN DESCRIPTION

Feedlot	Pen	Treatment	Width m	Depth m	Area m^2	Number of Cattle per pen	Stocking Density, m^2/head
A	1	Shaded	36	54	1944	160	12.1
A	2	Shaded	36	54	1944	161	12.1
A	3	Unshaded	36	54	1944	160	12.1
A	4	Unshaded	36	54	1944	160	12.1
B	H1	Shaded	49.8	64.6	3217	239	13.5
B	H2	Shaded	51	64.6	3295	225	14.6
B	H4	Unshaded	51	64.6	3295	239	13.8
B	H5	Unshaded	48	64.6	3101	233	13.3

Feed bunks were located at the top end of the pen slope at the opposite end to the watering points as shown in Figure 8 and Figure 9 for Feedlot A and B respectively. This maximises the distance between the two input sources, which is important in minimising fouling by grain carried on the muzzles of cattle after feeding. The average size of the feed bunks at both Feedlot A and B were 0.7 m wide with a depth of 0.5 m. This allowed a feeding space of 337 mm and 213 mm per head for Feedlot A and B respectively. Therefore the bunk space at Feedlot A allowed more cattle to feed at any one time when compared with Feedlot B.

The water troughs at Feedlots A and B were located at the lower end of the pen slope and had a float valve system installed that allowed the trough to automatically fill when the water level dropped. The water trough at Feedlot A was made of concrete and measured 3.4 m long x 0.48 m wide x 0.2 m deep. It had a holding capacity of 326 litres and provided an average drinking space of 21 mm/head. The water trough at Feedlot B was made of fibreglass and measured 2.5 m long x 0.44 m wide x 0.2 m deep. It had a holding capacity of 220 litres and provided an average drinking space of 11 mm/head. The troughs at both feedlots were cleaned on average every three days. This process involved scrubbing the troughs and flushing 5-10 litres of water through the pipelines to remove spilt grain and any algae that may have deposited on the walls.

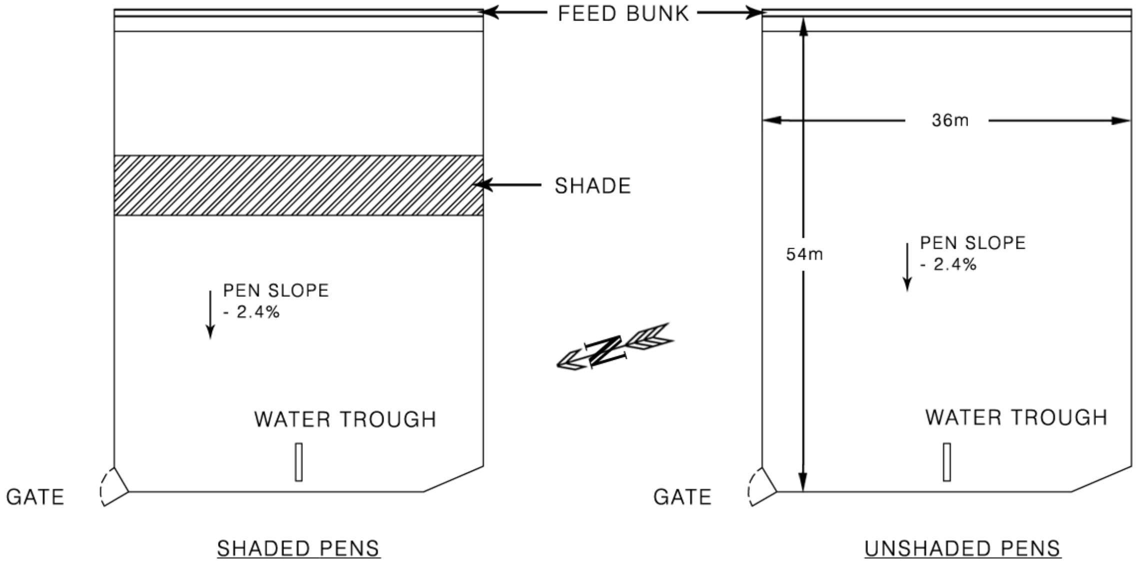


FIGURE 8 - FEEDLOT A PEN LAYOUT

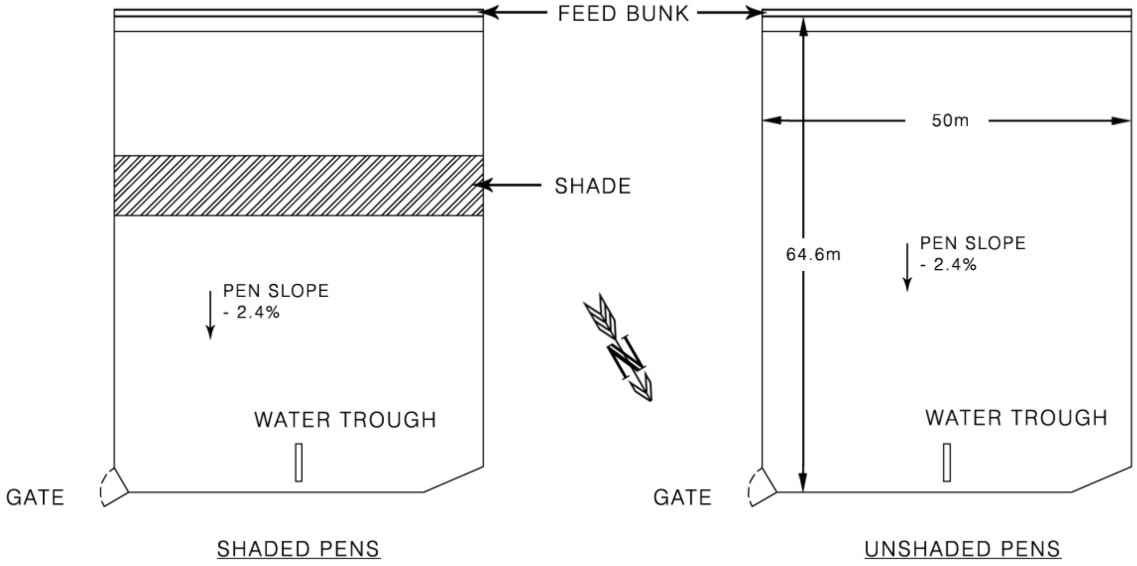


FIGURE 9 - FEEDLOT B PEN LAYOUT

6.3.2 Shade

The shade provided in the shaded pens at both feedlots varied between pens and between feedlots. Table 3 illustrates the type of shade and area of shade provided in each of the trial pens at Feedlots A and B.

TABLE 3 - TYPE, AREA AND PERCENTAGE OF SHADE IN TRIAL PENS AT FEEDLOT A AND B.

Feedlot	Pen	Shade Type	Area of Shade, m^2	Effective Area of Shade, m^2	Shade m^2/head	Percentage Shade %
A	3	Shade cloth	378	378	2.36	19.4
A	4	Shade cloth	378	378	2.36	19.4
B	H4	Corrugated Iron	598	598	2.50	18.6
B	H5	Corrugated Iron	598	459	2.04	13.9

At Feedlot A, the shade was provided by shade cloth which covered an area of 378 m^2 . The shade cloth allowed 20 % of the radiant light to penetrate. This equates to 19.4 % of the total pen area covered by shade.

At Feedlot B, the shade was provided by corrugated iron and covered an area of 598 m^2. For Pen H4 the corrugated iron provided a total impenetrative cover which gave an effective shaded area of 598 m^2 in the pen. This equated to 18.6 % of the total pen area covered by shade. For pen H5, the corrugated iron allowed 25 % of the light to penetrate, therefore realistically only providing an effective shaded area of 459 m^2 or 13.9 % of the total pen area covered by shade.

The shading was orientated close to a north-south direction at Feedlot A and a north-east to south-west direction at Feedlot B. The amount of light that could penetrate the shading was taken into consideration when statistically analysing for effects of shade (Sanders et al.1994).

6.3.3 Cattle Management

6.3.3.1 Feeding

Feedlot A and Feedlot B fattened cattle to Japanese market type specifications. However management techniques to achieve these standards differed significantly. Diet composition, time of feeding, quantity of feed delivered and frequency of feeding all varied according to environmental fluctuations, the condition of the cattle and the feedlot.

Feed delivery is a critical operation and was timed and closely monitored at both feedlots. At Feedlot A, feeding times were consistent with all cattle fed at least twice daily at approximately 9 am and 1 pm and occasionally at 3.30 pm. Two-thirds of the required daily feed intake was delivered at 9 am. The feeding regime was more varied at Feedlot B, as cattle were fed at no fixed times. Most days, cattle received at least three deliveries, with four being the maximum. At both feedlots, cattle were fed smaller quantities more frequently when exposed to unfavourable environmental conditions, such as high relative humidity or occasions of high precipitation.

The diet composition over the duration of the trial and between feedlots varied slightly with cattle at Feedlot A fed mainly dry rolled barley with forage hay, molasses, whole cottonseed and premix. At Feedlot B, the bulk of the feed comprised reconstituted barley and dry rolled barley with varying proportions of straw, molasses and premix.

The average moisture content of the total diet at Feedlot A was 13.3 % which was lower than that recorded at Feedlot B (21.5 %). The type of grain processing system employed at Feedlot B is a plausible explanation for the higher recorded moisture content.

6.3.3.2 Drinking Water Source and Quality

Both Feedlots A and B rely on bore water as their only source of drinking water. The measured total dissolved salts (TDS) in drinking water at Feedlot B averaged 3,275 mg/litre whilst at Feedlot A an average TDS level of 1,606 mg/litre was recorded.

6.3.3.3 Breed and Origin

The predominant cattle type in both monitored pens at both feedlots over the duration of the trial was a heterogeneous mix of *Bos taurus* breeds. The breeds present included Charolais, Angus, Hereford, Murray Grey and Shorthorn, with a large proportion of stock being cross-breds.

Approximately 70% of Feedlot A cattle were of New South Wales origin, sourced from Roma Saleyards with the remaining sourced from other areas of Queensland. At Feedlot B, cattle monitored during the trial arrived at the feedlot in mid October with 75% sourced from New South Wales and the remainder from Queensland. The cattle monitored during the trial arrived at their respective feedlots between late September and mid October 1993.

6.3.3.4 Pen Allocation

The cattle involved in the trial were assigned to their pens at the start of November 1993. At Feedlot B, cattle were sorted to ensure equivalent numbers per pen. At Feedlot A, cattle were sorted and penned according to weight, which aimed to minimise weight differences per pen whilst maintaining an equivalent stocking density.

Although the initial stocking density was fairly consistent per pen for each feedlot, the pen numbers varied slightly over the duration of the trial. This was due to sick cattle which had to be removed to hospital pens for veterinary care, cattle occasionally escaped from pens or cattle management issues where cattle were returned to the wrong pens (Table 2/Table 3).

6.3.4 Manure Management

At Feedlot A, manure was removed from the pens as required and when conditions allowed and then stockpiled. At Feedlot B, pen manure was scraped as required and when conditions allowed and then mounded in the pen area. The mounds were located in the middle of the pen and were short-term structures. The mounds of manure were removed from the pen and placed in a stockpile after the cattle were dispatched.

6.4 Data Collection

6.4.1 Meteorological Data

Site-specific meteorological data was collected from both Feedlot A and Feedlot B to allow relationships between water consumption and meteorological conditions to be evaluated.

At Feedlot A, an automatic weather station (*Monitor Sensor®)* was setup and consisted of a data logger, a solar panel which charged a 6- volt battery and meteorological sensors for measuring air temperature, black globe temperature, relative humidity, global solar radiation, wind speed, wind direction, and rainfall. Sensors were placed in both unshaded and shaded pens.

At Feedlot B, an existing weather station consisting of a data logger, a solar panel which charged a 6 volt battery and meteorological sensors for measuring air temperature, black globe temperature, relative humidity, global solar radiation, wind speed, wind direction, and rainfall was used. At this site, the variables were recorded without discriminating between the microenvironments experienced under the shade and unshaded pens.

Measurements were undertaken at 1 minute intervals with an average recorded every hour. Maximum and minimum values were recorded daily and instantaneous values recorded at 3 pm. The following measurements were recorded:

Feedlot A:

- Ambient air temperatures: Unshaded and Shaded - max, min, mean (°C)
- Black globe temperatures: Unshaded and Shaded - max, min, mean (°C)
- Relative humidity: Unshaded and shaded (%RH)
- Global solar radiation: Unshaded and shaded (MJ/m^2)
- Wind speed (km/hr)
- Rainfall (mm).

Feedlot B:

- Ambient air temperatures: Unshaded - max, min, mean (°C)
- Black globe temperatures: Unshaded - max, min, mean (°C)
- Relative humidity: Unshaded (%RH)
- Global solar radiation: Unshaded (MJ/m^2)
- Wind speed (km/hr)
- Rainfall (mm).

Meteorological data was downloaded every two to four weeks from the weather stations. Downloaded data was transferred from the data loggers to a laptop computer using system software. The system uses "*Monitor Sensor*" *Logger*® software. The weather stations were cleaned after each download.

6.4.2 Water Consumption

A flow meter was installed at the water trough in each pen used in the trial to record water consumption. Meters mechanically recorded water flow (litres) and were connected to data loggers which recorded the water consumption every 6 minutes. Ten consecutive readings were summed to provide hourly measurements. The data loggers used were *"Rimik®"* Boss Four Channel Data Loggers and each logger was powered by a 12-volt battery.

For the purposes of this experiment, water consumption included water used for drinking, spillage, evaporation and trough cleaning. However, losses associated with spillage, evaporation and trough cleaning, estimated at approximately 0.28-2 L/head/day (Part A report), are small when compared with the generally accepted estimate of 50 L/650 kg LWT/day of drinking water consumption.

The water meters from Feedlot A were calibrated. The calibration showed differences between the electronic measurement and actual volume of flow. One meter measured flow volumes 8% below actual volumes. The data was adjusted accordingly.

The water meters at Feedlot B were calibrated to determine whether change in inlet pipe diameter at the entrance to the water meters affected the recorded flow rate. The calibration indicated that the reduction in inlet diameter did not affect the recorded flow.

Water meter data was downloaded every two to four weeks from the data loggers. The system used *Bossdata*® software.

A minor problem arose with the linking of water consumption files. In these cases, there was often up to 30 minutes of unrecorded data due to down loading and servicing time. It was assumed that the cattle were not drinking during these times as staff were near the troughs, hence the consumption was zero. Most files were three to four weeks long, hence only one in 20 to 25 days was affected, and then for less than 30 minutes.

6.4.2.1 Weight

Cattle in the shaded and unshaded experiment pens at both feedlots were weighed three times in total over the duration of the trial. Individual weighing scales available on each feedlot were used for this purpose. Where possible, cattle were weighed on entry and exit to the feedlot, with one other weighing approximately halfway through the trial. Cattle weighing was completed over two consecutive mornings with cattle removed from their pens one to three hours before weighing. It was important not to over-exert the cattle during the hotter periods of the day, especially during the last 70-80 days of the fattening period. Any handling, including weighing can be stressful for cattle. It was for this reason the final weights of the cattle leaving Feedlot B were derived from a representative sample of roughly 19 head per pen rather than all the cattle in the pen. The liveweights from this sample group were summed and then averaged to give an estimation of the pens average liveweight.

The cattle weight data enabled determination of an average daily gain per head per day and then allowing an average daily liveweight per head to be calculated.

The cattle involved in the trial were assigned to their pens at the start of November 1993. At Feedlot B, cattle were sorted to ensure equivalent numbers per pen. At Feedlot A, cattle were sorted and penned according to weight, which aimed to minimise weight differences per pen whilst maintaining an equivalent stocking density.

Cattle at Feedlot A were weighed on the 7th of December 1993, 12th of January 1994 and the 23rd of March 1994. Cattle at Feedlot B were weighed on the 1st of Nov 1993, 7th January 1994 and the 12th of March 1994. Table 4 illustrates the intake, exit and average liveweight for each pen involved in the trial. Average cattle weights at Feedlot A on the 7th December approximately 1 month into the trial were approximately 560 kg and exited at 681 kg. At Feedlot B cattle entered at 487 kg and exited at 668 kg.

TABLE 4 - INTAKE, EXIT AND AVERAGE LIVEWEIGHTS FOR CATTLE IN SHADED AND UNSHADED PENS OVER THE DURATION OF THE TRIAL AT FEEDLOT A AND B.

Feedlot	Pen		No. Head	Avg Intake LWT kg	Avg Exit LWT kg	Mean LWT kg	Average Daily Gain kg/day
A	1	Shaded	160	569.8	690.4	632.4	1.15
A	2	Shaded	161	553.8	675.7	616.1	1.23
A	3	Unshaded	160	561.7	681.4	618.0	1.19
A	4	Unshaded	160	553.8	675.7	621.9	1.27
B	H1	Shaded	239	486.6	666.9	588.4	1.37
B	H2	Shaded	225	494.3	656.3	589.4	1.23
B	H4	Unshaded	239	484.7	668.2	586.3	1.39
B	H5	Unshaded	233	480.4	681.6	589.7	1.52

6.4.2.2 Feed Intake

Weekly data on diet type including main grain type, processing method, silage and roughage percentage, moisture content along with total consumption as fed (kg) on shaded and unshaded pens was collected from Feedlot A and B. This allowed an average as-fed feed intake to be determined. The as-fed intake was converted to a daily dry matter intake using the average moisture content of the diet (13.3%) and (21.4%) for Feedlot A and B respectively.

TABLE 5 - AVERAGE DRY MATTER INTAKE PER HEAD PER DAY FOR SHADED AND UNSHADED PENS OVER THE DURATION OF THE TRIAL AT FEEDLOT A AND B

Feedlot	Pen		Feed Intake As-Fed kg/hd/day	Dry Matter Intake kg DM/hd/day	Dry Matter Intake g/kg LWT
A	1	Shaded	13.6	11.8	17.4
A	2	Shaded	14.2	12.3	20.2
A	3	Unshaded	13.6	11.8	19.1
A	4	Unshaded	12.8	11.1	17.9
B	H1	Shaded	15.4	12.1	18.1
B	H2	Shaded	15.1	11.9	20.1
B	H4	Unshaded	15.1	11.9	20.3
B	H5	Unshaded	15.1	11.9	20.2

7 Results and Discussion

7.1 Collation of Raw Data

Equipment used for collecting site data was described in Section 6.4. Cattle weight and feed intake are discussed and summary data presented in Section 6.4. Weather data was extracted from the data file using *Logger* software in conjunction with a configuration file. Periods of water meter data and weather station data were lost at both feedlots due to mechanical and/or electronic failure, destruction of equipment by cattle, and human error. Where possible, this data was filled with data from other locations or sources.

Raw water meter data was converted from a binary format to a useable ASCII format using the *Bosslogger*® software. Once in this format, the data was imported into an excel spreadsheet where the 6-minute data was totalled into hourly and daily water consumptions. Diurnal plots of water consumption were made so that peak consumptions and the time they occurred could be extracted from the data.

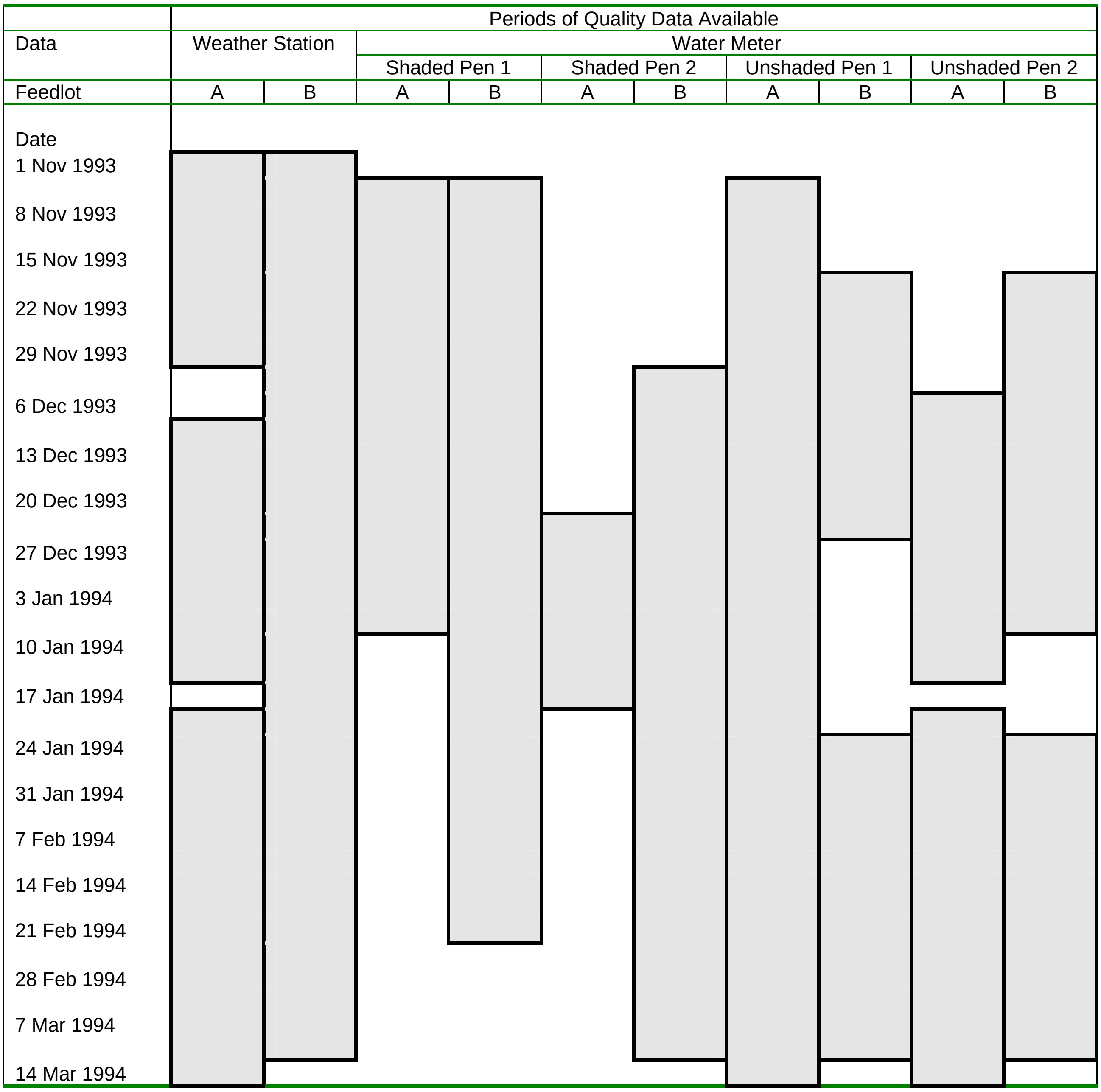
Early in the trial, problems were encountered with the water meters becoming blocked with sediment. Water filters were installed to address this problem. The filters were cleaned each time the site was serviced.

After all of the raw electronic (weather/water meter) data was entered, other manually recorded data such as cattle numbers, liveweights, time of feeding and ration quantities were entered manually into the spreadsheet.

The results for each treatment were averaged, giving single values for the shaded and unshaded pens at both feedlots.

Table 6 shows the periods through the trial for which good quality data is available from the various recording sources. The periods marked as having good quality data available still had occasional records missing, but were largely intact. The periods of quality data were not well aligned between the different recording devices, limiting the period available for direct comparison of all treatments. However, substantial data was collected successfully and this data has been assessed for general trends.

TABLE 6 - DATA COLLECTION DURING THE TRIAL PERIOD



▨ - Denotes periods for which good quality data was available

7.2 Diurnal variation in water consumption

The diurnal variation of consumption has been assessed during the data analysis. Diurnal variation influences demand throughout the day and is an important design component of the feedlot water supply and distribution system.

Daily water consumption patterns were assessed by plotting water consumption levels through the day for a period of seven days. Periods were chosen where data sets were complete and corresponded with 26/12/93 to 01/01/94 and 23/01/94 to 29/01/94 at Feedlot A and Feedlot B respectively.

The Feedlot A trial period was characterised by maximum daily ambient temperatures of 28 – 38°C, typically peaking around 4 pm and minimum daily temperatures of 11 – 19°C, typically around 5 am. The heat load index calculated according to the equation presented in Gaughan (2004) gave maximum daily values of 84 – 109 and minimum daily values of 41 – 55. The daily maximum heat load index value occurred within the period between 8 am – 4 pm, while the daily minimum heat load index value occurred within the period between 10 pm – 5 am.

The Feedlot B trial period was characterised by maximum daily ambient temperatures of 28 – 31°C, typically peaking around 2 – 4 pm and minimum daily temperatures of 14 – 20°C, typically around 4 – 6 am. The heat load index calculated according to the equation presented in Gaughan (2004) gave maximum daily values of 77 – 97 and minimum daily values of 49 – 56. The daily maximum heat load index value occurred within the period between 10 am – 3 pm, while the daily minimum heat load index value occurred within the period between 9 pm – 6 am.

The pattern of water consumption through the day was influenced by the heat load index peak value. Days with peak heat load index values <90 generally showed a morning peak and a larger and longer afternoon peak. Water consumption on days with peak heat load index values >90 showed a similar pattern in water consumption with higher rates over a longer period, particularly in the afternoon and between nightfall and midnight.

The diurnal variation in water consumption was generally similar across all pens at both sites. Figure 10 and Figure 12 illustrate the typical variation for shaded pens while Figure 11 and Figure 13 illustrate the typical variation for unshaded pens. The typical daily variation is summarised as follows:

- Very low consumption in the period 3 am – 5 am.

This period generally ends when the heat load index starts to increase substantially. Actual consumption during this period appears to be influenced by the heat load index values from the previous day (i.e. higher consumption where higher index peak values (>90) occur, very low consumption over a longer period where lower index peak values (<90) occur).

- Greatest water consumption within the period 6 am – 6/8 pm.

This period generally begins when the heat load index starts to increase rapidly and ends soon after the heat load index decreases rapidly. Average consumption during this period appears to be influenced by the heat load index values for the day (i.e. higher consumption where higher index values occur). On days with higher heat load index peak values (>90), water consumption in the period following 2 pm is generally sustained at higher rates than during the period prior to 2 pm. On days with lower heat load index peak values (<90), consumption throughout the day is generally more consistent (i.e. trends in the data are less pronounced). Large variations in water consumption between 6-minute periods occur throughout the day for all pens. The general trend to higher water consumption in the afternoon is also likely to reflect in part the trend to higher feed consumption during this period.

- Generally low water consumption from 8 pm – 9 pm for 1-2 hours.

A period of low water consumption generally occurs for 1 – 2 hours at approximately 8 – 9 pm. This period occurs following the rapid decrease in heat load index that occurs at the end of the afternoon. The peak value of the heat load index for the day does not appear to influence the length of this period, or the water consumption during the period.

- Increased water consumption from 9 pm for 2-3 hours.

Water consumption during this period is typically 30 – 50% of morning water consumption, and appears to be influenced by the heat load index values for the day (i.e. higher consumption where higher index values occur).

- Gradual decrease in water consumption to minimal levels by 3 am.

This period is the transition from night watering to rest. Actual consumption during this period appears to be influenced by the heat load index values from the previous day (i.e. higher consumption for longer where higher index peak values (>90) occur, lower consumption over a shorter period where lower index peak values (<90) occur).

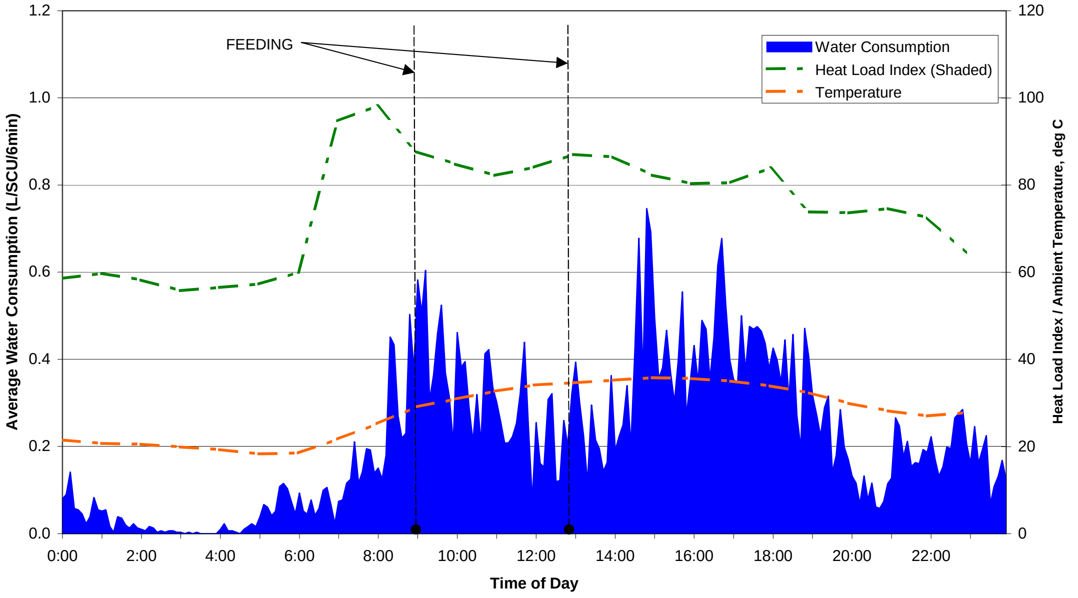


FIGURE 10 - DIURNAL VARIATION IN WATER CONSUMPTION – FEEDLOT A SHADED PEN 26 DEC 1993

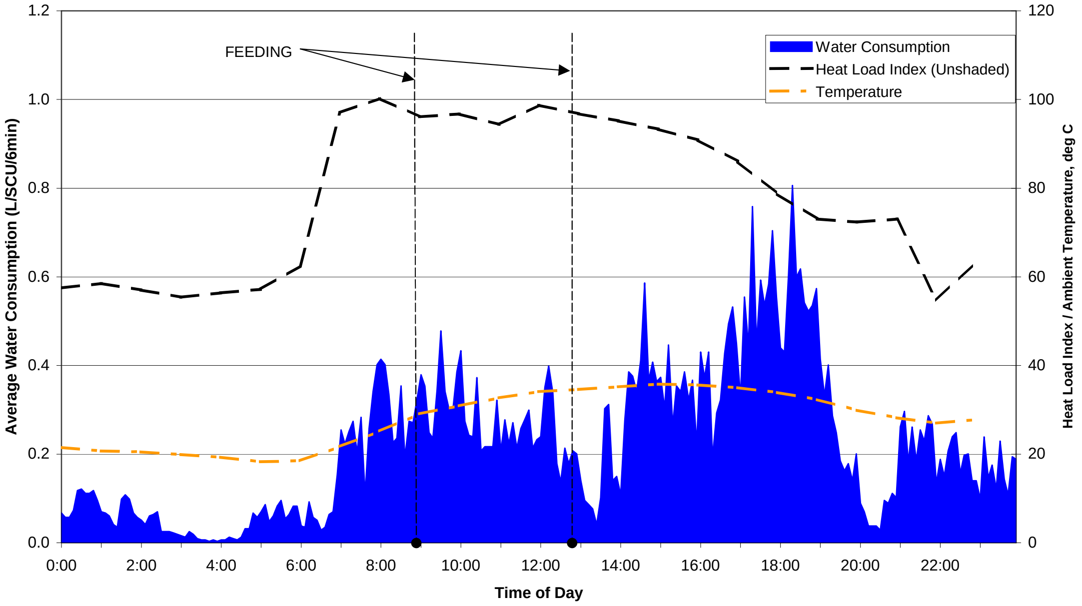


FIGURE 11 - DIURNAL VARIATION IN WATER CONSUMPTION – FEEDLOT A UNSHADED PEN 26 DEC 1993

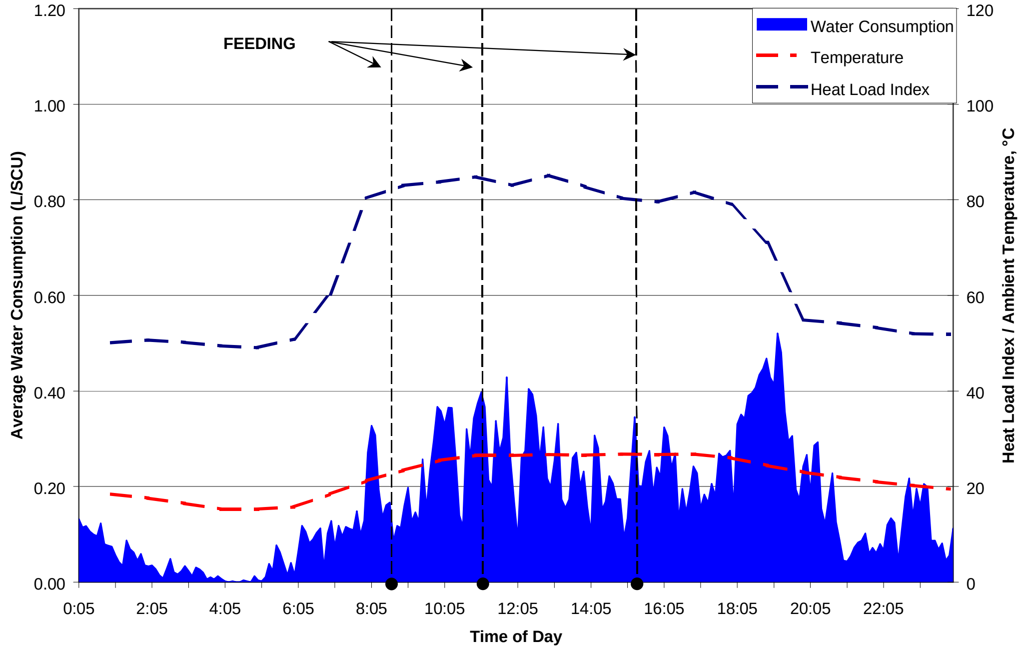


FIGURE 12 - DIURNAL VARIATION IN WATER CONSUMPTION – FEEDLOT B SHADED PEN 26 JAN 1994

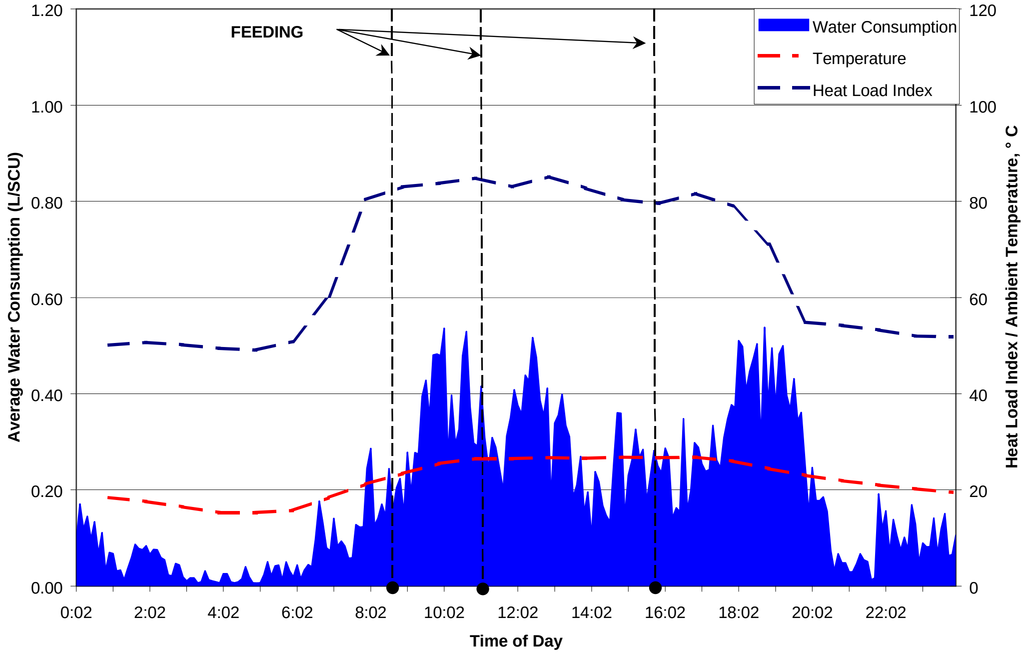


FIGURE 13 - DIURNAL VARIATION IN WATER CONSUMPTION – FEEDLOT B UNSHADED PEN 26 JAN 1994

7.2.1 Water Consumption Rates

The Feedlot A trial period was characterised by maximum daily ambient temperatures of 28 – 38^{o}C, typically around 4 pm and minimum daily temperatures of 11 – 19^{o}C, typically around 5 am. In this review the data has been standardised to a standard cattle unit (SCU), that is, with reference to a 600 kg liveweight animal. Peak water consumption varied between 3.4 – 5.7 l/SCU/hour for shaded pens and between 3.9 – 7.7 l/SCU/hour for unshaded pens. Peak consumption occurred within the period 9 am – 7 pm for shaded pens and 8 am – 7 pm for unshaded pens. Minimum water consumption was 0 l/SCU/hour for all pens, generally between 3 am – 5 am. Water consumption rates averaged over each day across shaded pens (1.5 – 2.1 l/SCU/hour) were 83 – 97% of average water consumption rates in unshaded pens (1.9 – 2.2 l/SCU/hour).

The Feedlot B trial period was characterised by maximum daily ambient temperatures of 28 – 31^{o}C, typically around 2 – 4 pm and minimum daily temperatures of 14 – 20^{o}C, typically around 4 – 6 am. Peak water consumption varied between 3.4 – 5.5 l/SCU/hour for shaded pens and between 4.1 – 4.8 l/SCU/hour for unshaded pens. Peak consumption occurred within the period 9 am – 8 pm for shaded pens and 9 am – 7 pm for unshaded pens. Minimum water consumption was 0 l/SCU/hour for all pens, generally between 3 am and 5 am. Water consumption rates averaged over each day across shaded pens (1.7 – 1.8 l/SCU/hour) were 85 – 91% of average water consumption rates in unshaded pens (1.9 – 2.0 l/SCU/hour).

Hourly water consumption rates have been compared to average ambient temperature and not heat load index, as temperature data is widely available and well understood. Water consumption rates during a day generally follow ambient temperatures, i.e. highest consumption during the hottest parts of the day and lowest consumption during the coolest part of the day. The magnitude of peak water consumption generally follows maximum daily ambient temperatures, i.e. higher peak consumption on hotter days. Total daily water consumption showed limited variation between the days included in the trial, while peak consumption varied substantially where the maximum daily ambient temperature changed through the trial period. Figure 14 to Figure 17 show the hourly water consumption records for the trial periods at each feedlot. The total daily water consumption is averaged over 24 hours on these graphs (i.e. daily average water consumption = daily total water consumption / 24 hours).

Feedlot A showed the most variation in peak water consumption, occurring within unshaded pens. This result may reflect the greater range in maximum ambient temperatures recorded over the trial period at this site. Feedlot B showed greater variation in peak water consumption for shaded pens. Maximum ambient temperatures at this site were at the lower end of the range observed at Feedlot A, and were more consistent.

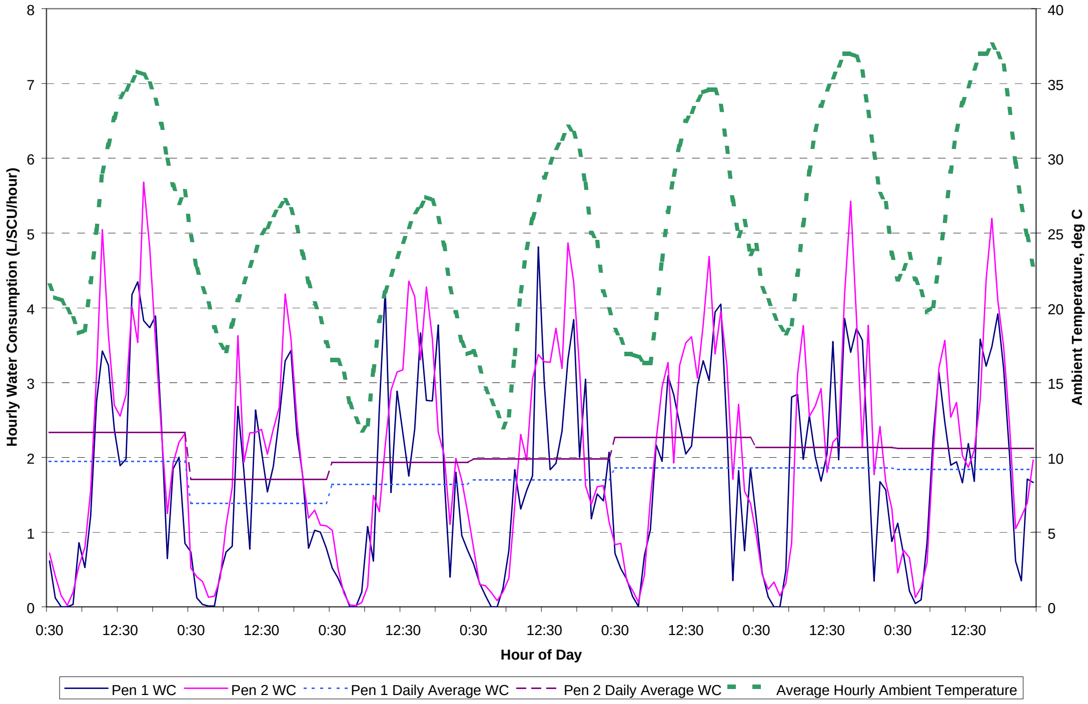


FIGURE 14 - HOURLY VARIATION IN WATER CONSUMPTION (WC) – FEEDLOT A SHADED PEN

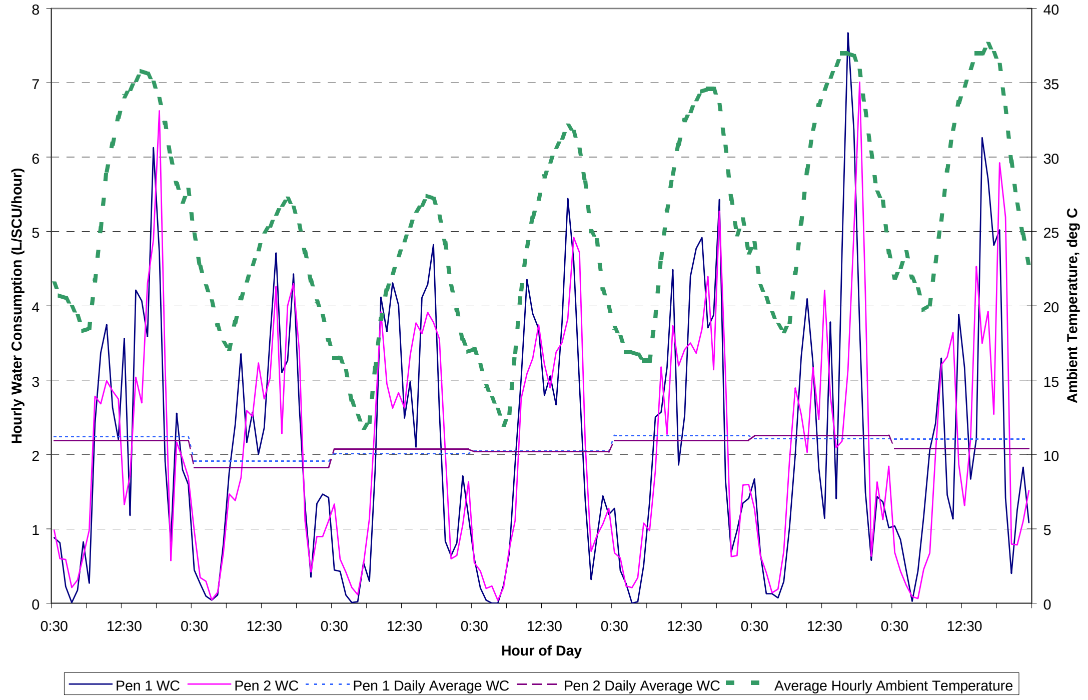


FIGURE 15 - HOURLY VARIATION IN WATER CONSUMPTION (WC) – FEEDLOT A UNSHADED PEN

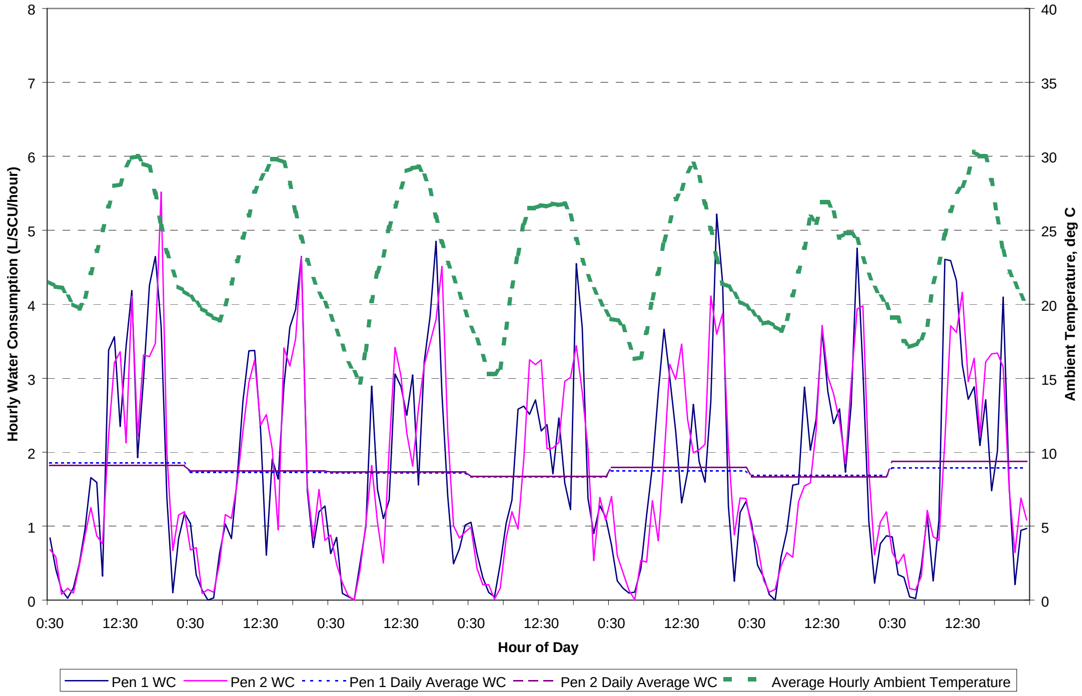


FIGURE 16 - HOURLY VARIATION IN WATER CONSUMPTION (WC) – FEEDLOT B SHADED PEN

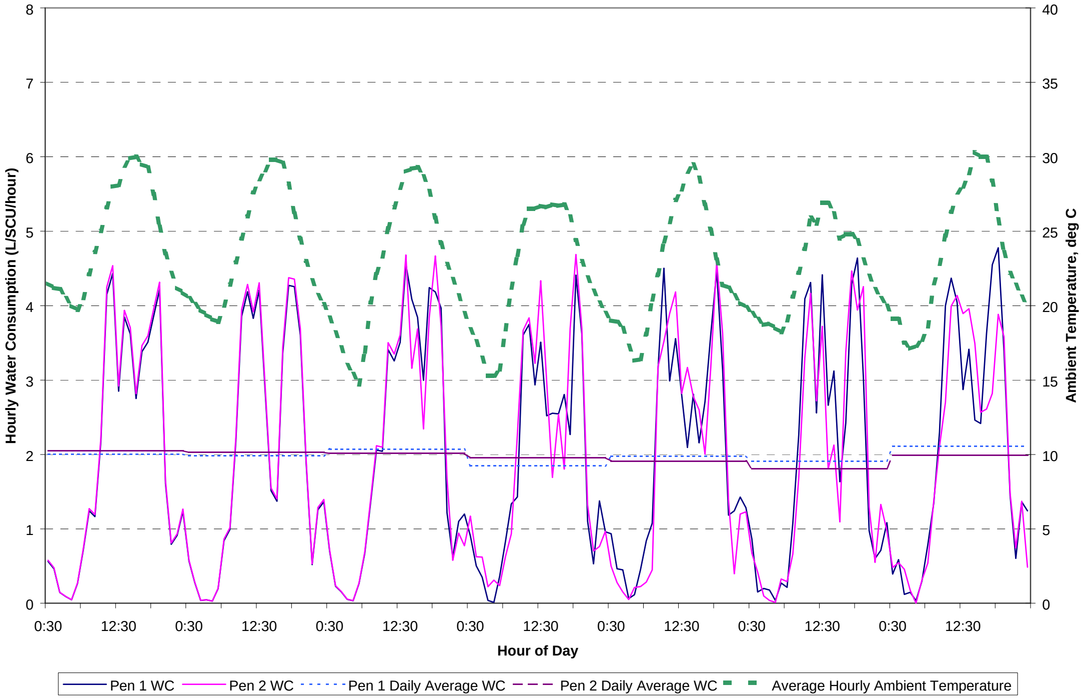


FIGURE 17 - HOURLY VARIATION IN WATER CONSUMPTION (WC) – FEEDLOT B UNSHADED PEN

7.3 Daily Water Consumption

Daily water consumption is a useful parameter to be assessed as it allows annual water requirements to be determined. This is an important design and operational consideration. In this review the data has been standardised to a standard cattle unit (SCU), that is, with reference to a 600 kg liveweight animal.

Daily water consumption data was recorded for both feedlot sites. However, complete data records are only available over limited periods of time. Furthermore, the periods of complete data only partially match up between shaded and unshaded pens and between feedlot sites (see Table 6).

The trial period at Feedlot A had complete data for all pens over 16 days from 21/12/93 – 5/1/94. Maximum daily temperatures during this period were between 20.2 – 31^{O}C. Daily water consumption varied between 33.5 – 56.8 l/SCU/day for shaded pens and between 33.6 – 59.4 l/SCU/day for unshaded pens. The minimum daily consumption occurred on a day with 61.4 mm of rain and a maximum temperature of 33.7^{O}C, while the maximum daily consumption occurred on a day with no rainfall and a maximum temperature of 40.2^{O}C.

Complete data was available for both unshaded pens in Feedlot A over approximately 90 days each for most of the period from mid-December 1993 to mid-March 1994. The minimum water consumption was 16.2 and 12.6 l/SCU/day with maximum temperature of 21.7 and 22.2^{O}C and rainfall of 34.6 and 41 mm, respectively. The maximum water consumption was 59.9 and 60.3 l/SCU/day on a day with no rainfall and a maximum temperature of 43.5^{O}C. Average water consumption on days with rainfall >10 mm was 21.1 and 18.9 l/SCU/day, while average water consumption for all other days was 49 and 46.1 l/SCU/day respectively.

The trial period at Feedlot B had complete data for all pens over 19 days from 2/12/93 – 20/12/93 and over 30 days from 23/1/94 – 21/2/94. Maximum daily temperatures during this period were between 20.7 – 35.3^{O}C. Daily water consumption varied between 10.8 – 54.7 l/SCU/day for shaded pens and between 11.6 – 60.5 l/SCU/day for unshaded pens. The minimum daily consumption occurred on a day with 43 mm of rain and a maximum temperature of 21.2^{O}C, while the maximum daily consumption occurred on a day with no rainfall and a maximum temperature of 34.8^{O}C.

Complete data was available for both shaded pens in Feedlot B over approximately 100 days each for different periods from November 1993 to mid-March 1994. The minimum water consumption was 11.8 and 10.8 l/SCU/day with maximum temperature of 21.4 and 21.2^{O}C and rainfall of 19 and 43 mm, respectively. The maximum water consumption was 63.8 and 65.3 l/SCU/day on a day with no rainfall and a maximum temperature of 41.6^{O}C. Average water consumption on days with rainfall >10 mm was 31.9 and 27.8 l/SCU/day, while average water consumption for all other days was 44.5 and 43.2 l/SCU/day respectively.

Complete data was available for one unshaded pen in Feedlot B over approximately 90 days for much of the period from mid-November 1993 to mid-March 1994. The minimum water consumption was 12.8 l/SCU/day with a maximum temperature of 21.2^{O}C and rainfall of 43 mm. The maximum water consumption was 63.5 l/SCU/day on a day with no rainfall and a maximum temperature of 35.5^{O}C *(the day corresponding to maximum water consumption in shaded pens was not part of this* *data)*. Average water consumption on days with rainfall >10 mm was 26.5 l/SCU/day, while average water consumption for all other days was 46.7 l/SCU/day.

The available data suggests that temperature and rainfall both influence the daily water consumption rates, as shown in Figure 18 and Figure 19. The change in water consumption with variation in climate was broadly consistent over time, i.e. higher water consumption with higher ambient temperature and lower water consumption with rainfall events. However, the extent of changes in water consumption with variation in climate was not consistent over time, i.e. an increase in ambient temperature of $5^{O}C$ did not always cause the same increase in water consumption. This suggests that a range of factors influence water consumption in combination.

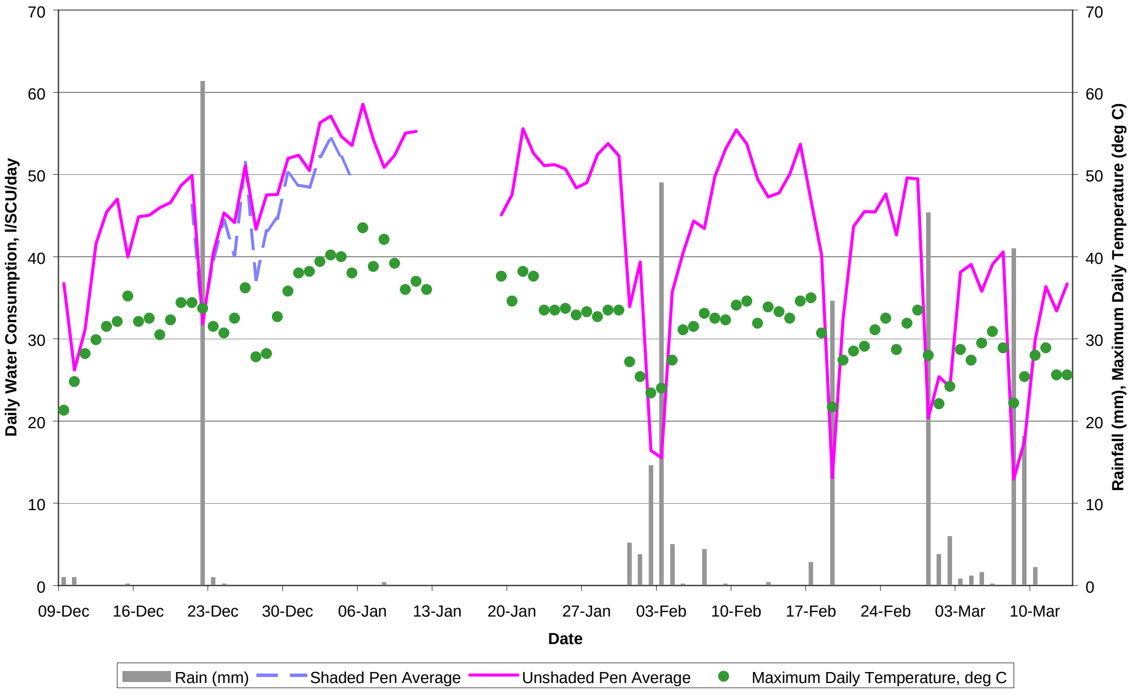


FIGURE 18 - INFLUENCE OF CLIMATE ON DAILY WATER CONSUMPTION – FEEDLOT A

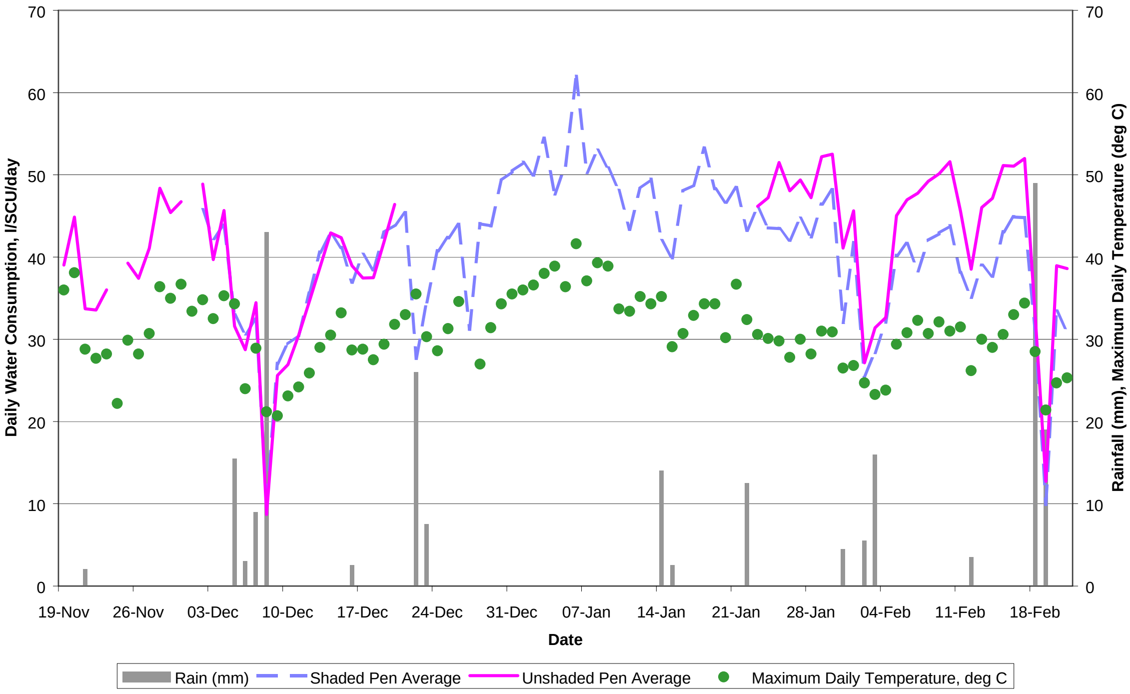


FIGURE 19 - INFLUENCE OF CLIMATE ON DAILY WATER CONSUMPTION – FEEDLOT B

7.3.1 Variables Affecting Daily Water Consumption

Sanders et al. (1994) analysed hourly data over the full duration of the trial period. Lyndon (1994) analysed hourly data for two days of observation for each feedlot. The days selected included the 2/12/1993 and the 16/2/1994 for Feedlot A and 16/12/1993 and the 17/12/1993 for Feedlot B. These days were selected on the basis of completeness of data (Lyndon 1994).

Sanders et al. (1994) determined that a 'per 100kg live weight' representation rather than a ‘per head’ basis was the most appropriate way of representing the results. This analysis was found to normalise the data and remove the per head differences in weight that can occur within and across pens. Knowing that cattle of different weight consume different quantities of water (Watts, Tucker & Casey 1993), it can be seen that analysis on the basis of cattle numbers may not pick up differences between pens. Sanders et al. (1994) found that using the 'per live weight' representation over per head consistently improved the variance by 2% to 9% in the data set. Lyndon (1994) analyses were completed on a per head basis.

Sanders et al. (1994) and Lyndon (1994) used a 'Best Subset Regression Analysis' within *Statistix*® to determine the variables that appeared to significantly influence water consumption. Sanders et al. (1994) found the most important factors in decreasing order of importance (percent variance explained) to be:

- solar radiation
- relative humidity
- average daily temperature
- rainfall
- dry matter intake

Sanders et al. (1994) found black globe temperature to have a more significant influence on daily water consumption than average daily temperature. However, as black globe temperature is strongly correlated with solar radiation and average ambient temperature Sanders et al. (1994) decided to use the latter variables as they are more commonly recorded parameters. Sanders et al. (1994) developed a weather factor which is a combination of solar radiation, relative humidity and average daily temperature.

Lyndon (1994) found temperature, relative humidity, solar radiation and wind speed as the variables with the most significant effect on water intake.

Sanders et al. (1994) reduced data sets so they contained the variables that explained some variance in the data set. *Genstat V*® was used to test these variables to see if they had a significant ($P<5\%$) influence on water consumption. This package was also used to test for the influence of feedlot, dry matter intake across feedlots, and shading across feedlots. These factors represent spatial variability of the parameters (Sanders et al. 1994).

Sanders et al. (1994) reported the following:

- Feedlot is a significant variable (P<1%).
- When the treatments were averaged there was no significant difference between average daily water consumption per 100 kg liveweight in shaded and unshaded pens. However, there is some variance (P<10%).
- Analysing treatments individually showed that there was a significant difference between average daily water consumption for shaded and unshaded pens within and across feedlots (P<2.5%).
- There is a significant difference between average daily water consumption for unshaded pens between feedlots (P<5%).
- There is not a significant difference between average daily water consumption for shaded pens between feedlots.
- There is a significant difference in climate across feedlots, and between shaded and unshaded treatments (P<1%).
- Dry matter intake differed significantly across feedlots (P<1%).
- The weather factor (function of temperature, radiation, and humidity) significantly influenced water consumption (P<1%).
- Rainfall has a significant effect on average daily water consumption (P<1%).

7.3.1.1 Influence of Shading on Water Consumption

The statistical analysis of Sanders et al. (1994) showed that Feedlot A water consumption per 100 kg liveweight was reduced on average by 4.8% with the use of shading. In 82% of cases, where there was data representing both shaded and unshaded pens, shading decreased water consumption. Feedlot B water consumption per 100 kg liveweight was reduced on average by 8.8% with the use of shading. In 85% of cases, where there was data representing both shaded and unshaded pens, shading decreased water consumption.

Sanders et al. (1994) noted there were instances where shading did not reduce water consumption. In these cases, factors such as high rainfall, cold temperatures, combinations of weather factors, or other unknown factors had more of an influence on water consumption than shading.

Sanders et al. (1994) evaluated the difference in water consumption between shaded and unshaded pens for various average temperature ranges. The results indicated that for low temperatures (around 20°C) the variance in consumption between shaded and unshaded pens was less than for higher temperatures (see Table 7). The difference in results between the two feedlots is largely due to the different climate data recorded e.g. higher average daily temperatures were recorded at Feedlot A.

TABLE 7 - INFLUENCE OF SHADING ON WATER CONSUMPTION (FROM SANDERS ET AL. 1994)

	Difference in water consumption between shaded and unshaded pens	
	Feedlot A	Feedlot B
Whole data set	4.8%	8.8%
Average daily temperature < 22^{O}C	2.1%	6.7%
Average daily temperature > 22^{O}C	5.4%	9.4%

The influence of shading on the diurnal variation in water consumption can be considered with respect to the pattern of water consumption previously identified:

- Very low consumption in the period 3 am – 5 am.

Generally, shaded pens show similar to longer periods of water consumption where lower peak values (<90) of heat load index occur the previous day, and similar to lower consumption rates. However, following days with higher peak values (>90) of heat load index, similar to slightly higher water consumption occurs in shaded pens, and similar to slightly shorter periods of very low water consumption.

- Greatest water consumption within the period 6 am – 6/8 pm.

Generally, unshaded pens have higher morning water consumption and higher afternoon water consumption over longer periods. Water consumption tends to remain elevated until later in the day for unshaded pens.

- Generally low water consumption from 8 pm – 9 pm for 1-2 hours.

During this period, water consumption is generally lower for a longer period in unshaded pens.

- Increased water consumption from 9 pm for 2-3 hours.

Shaded pens show similar to higher water consumption during this period, particularly at the start of the period.

- Gradual decrease in water consumption to minimal levels by 3 am.

Shaded pens show a slightly higher water consumption during this period.

Feedlot A has two days of records with maximum ambient temperatures in the range recorded for Feedlot B. These two days showed a similar pattern in hourly water consumption rates to that observed at Feedlot B, i.e. greater consistency in peak water consumption for the unshaded pens than for the shaded pens, and greater consistency in water consumption rates within each day. The higher variation in water consumption for shaded pens reflects low water consumption rates during the morning compared to unshaded pens.

Overall, unshaded pens showed higher peak hourly water consumption than shaded pens across the trial periods at both feedlot sites. Unshaded pens showed greater variability in water consumption than shaded pens during days having high ambient temperatures (>30^{o}C). Unshaded pens showed less variability in water consumption than shaded pens during days having lower ambient temperatures, due largely to higher morning consumption rates in the unshaded pens.

The average daily water consumption was slightly lower for shaded pens than for unshaded pens. Daily water consumption in both shaded and unshaded pens was influenced by climatic factors such as rainfall and ambient temperature. Shaded and unshaded pens had very similar response to variation in climate at times, but at other times variation in climate had a greater influence on the water consumption in unshaded pens (see Figure 18 and Figure 19).

7.3.1.2 Influence of Ambient Temperature on Water Consumption

Sections 7.2 and 7.3 have identified that water consumption rates do generally follow ambient temperatures. Figure 10 to Figure 19 show two different measures of ambient temperature – hourly average temperature and daily maximum temperature. Both of these measures follow the general pattern in water consumption, although considerable point-to-point variation exists in the relationship between water consumption and ambient temperature for each measure. This variation indicates that other factors also influence water consumption.

7.3.1.3 Influence of Dry Matter Intake on Water Consumption

The influence of dry matter intake (DMI) on water consumption has also been investigated. Figure 20 shows the variation in DMI through the trial period for Unshaded Pen 2 at Feedlot B. This variation is not replicated exactly within each pen, but illustrates the extent to which DMI can change from day to day. Figure 20 also shows that temperature and rainfall are a substantial influence on daily DMI.

Figure 25 and Figure 26 show water consumption as a function of DMI plotted against maximum daily ambient temperature. Three different series of water consumption are presented – rain days, non-rain days and days of a sudden, large change in DMI (i.e. a difference of 20-40% compared to previous days). Large variation is shown in the water consumption on rain days and days of large change in DMI. Non-rain days show a more consistent trend with change in maximum daily ambient temperature. This demonstrates that DMI does influence water consumption, but that other variables also have an influence.

One of the Feedlot A shaded pens showed an average daily water consumption that was consistently 15-20% higher than for the other shaded pen (Figure 14). Data recorded for the trial also showed a 5-10% higher DMI for the pen with the higher water consumption.

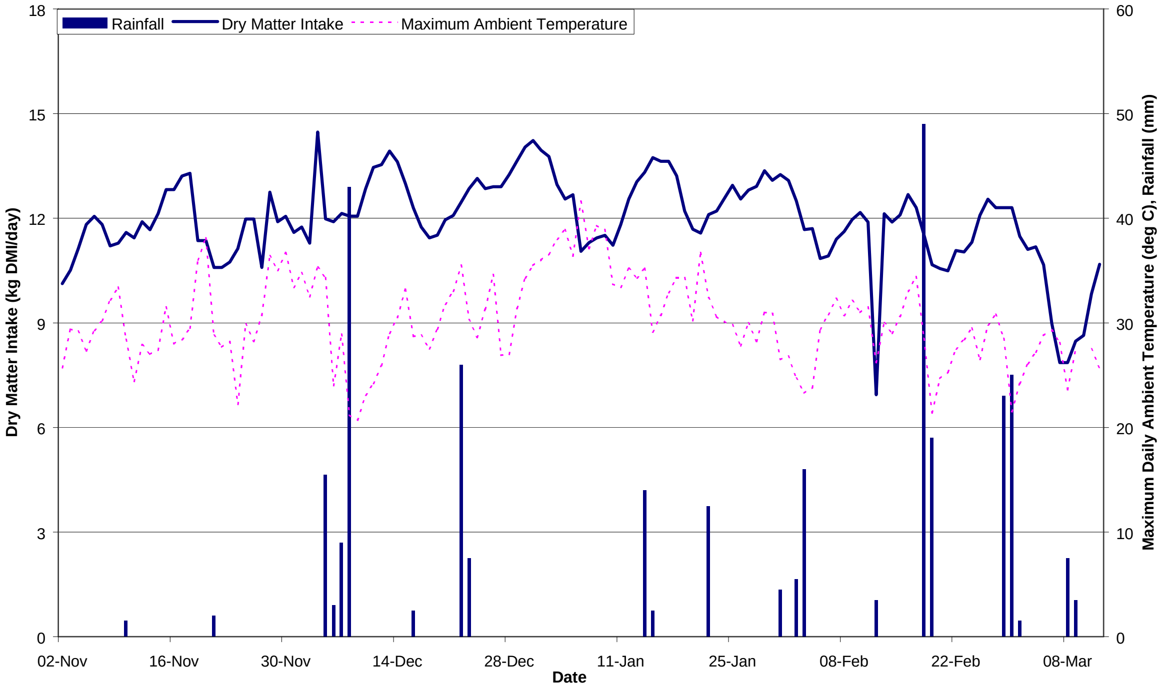


FIGURE 20 - VARIATION IN DRY MATTER INTAKE (DMI) FOR ONE UNSHADED TREATMENT PEN AT FEEDLOT B

7.3.1.4 Influence of Rainfall on Water Consumption

Rainfall causes a reduction in water consumption, as noted in Section 7.3. This effect is generally temporary, as shown in Figure 18 and Figure 19. The reduced water consumption may be due in part to reduced DMI and reduced ambient temperatures (Figure 20). Figure 25 and Figure 26 show larger variations in water consumption on rain days than on non-rain days. This large variation may be partly due to the sudden large reductions in DMI that often occur with rainfall events (Figure 20), but is also due to other factors (as shown by the large variation in Figure 27 and Figure 28).

7.4 Predictive Daily Water Consumption Models

7.4.1 Sanders et al. (1994) Water Consumption Model

Sanders et al. (1994) developed a predictive water consumption model which best represented the significant variables affecting the daily water consumption data set investigated. These variables included dry matter intake, rainfall and a weather factor representing the meteorological variables of solar radiation, average daily temperature and humidity. The weather factor accounted for the average difference in water consumption across feedlots, allowing for the creation of one predictive model for both feedlots.

The model was developed by averaging the shaded and unshaded treatments and then using the *Coplot®* program to obtain the best relationship between significant variables and water consumption on a 'per 100 kg live weight' basis (Sanders et al. 1994).

Shading was firstly represented as a categorical variable: '1' for shaded pens, and a '0' for unshaded pens in the model. The model was then tested to see whether representing shaded pens as a fraction of 1 depending on their degree of shading would produce a more predictive model. This method did not produce a more predictive model, hence shaded pens were represented as a '1' and unshaded pens were represented as a '0'. This indicates that, for the data collected, the amount of light penetrating the shading is not highly important.

A non-linear regression was used to model water consumption. The following equation provided the best fit:

$$WC = 1.337 - 0.037 \times R + 0.687 \times DMI + (1.592 - 0.199 \times SF) \times (\text{weather})^{0.5} \qquad \textbf{EQUATION 4}$$

Where:

WC = water consumption (L/100 kg LW)
R = Rainfall (mm)
DMI = Dry matter intake (kg) per 100 kg LW (kg/100 kg)
SF = Shading Factor, 0 for unshaded, 1 for shaded
Weather = Average Daily Temperature (^{o}C) x Solar Radiation (MJ/m2) / Relative Humidity (%)

Sanders et al. (1994) found the correlation coefficient (R^2) between predicted values and measured values of 0.78. The predictive model responds to increasing rainfall, humidity, and shading by decreasing water consumption. Conversely, the model responds to increasing dry matter intake, temperature, and solar radiation by increasing water consumption.

The model predictions for water consumption are compared to actual water intake in Figure 23 and Figure 24 for shaded and unshaded pens, respectively. Feed water for the grain-based rations used in the trial was 1 5 L/SCU/day, with average values of approximately 2.5 L/SCU/day. As a result, the Sanders et al. (1994) predicted water consumption shown in Figure 23 and Figure 24 would be expected to consistently under-predict actual water intake by 2-3 L/SCU/day.

7.4.2 Hicks et al. (1988) Water Intake Model

Hicks et al. (1988) measured the water intake of 239 crossbred steers with an average initial weight of 330 kg over a range of conditions in a 95-day trial. Ambient temperature and dry matter intake were the major factors affecting water intake. They developed a statistical relationship between water intake of feedlot cattle and other variables. Their formula (converted to metric units) is presented in Equation 3.

The measured water intake data was compared to predicted values from the model formulated by Hicks et al. (1988) assuming a dietary salt content of 0.3%. The model predictions are shown in Figure 23 and Figure 24 for shaded and unshaded pens, respectively.

7.4.3 Winchester and Morris Water Intake Model

Winchester and Morris (1956) provide data collected in a laboratory context relating water intake per day to ambient temperature, dry matter intake and breed. The results of this equation rise rapidly for temperatures above 30°C, particularly for *Bos taurus* cattle. Watts, Tucker and Casey (1994) undertook a statistical analysis of their data and found relationships between water intake and temperature (see Equation 1 and Equation 2).

These equations were both applied to the data collected during the trial period, with the results shown in Figure 21 and Figure 22. The predictions from the *Bos indicus* equation provide better agreement with the measured data. The *Bos indicus* predicted values for unshaded pens had less variation and were in the range of the measured values more consistently than the *Bos indicus* predicted values for shaded pens. The model predictions are also shown in Figure 23 and Figure 24 for shaded and unshaded pens, respectively.

Comparison of the results from the three predictive models with the measured data (Figure 23 and Figure 24) indicates that, under the conditions observed in the trial, all models tend to over-predict low water consumption (<40 L/SCU), but under-predict higher water consumption. However, the Winchester and Morris (*Bos indicus*) model provides a relatively accurate prediction of higher water consumption rates for shaded pens. All model results are generally within the range of measured data.

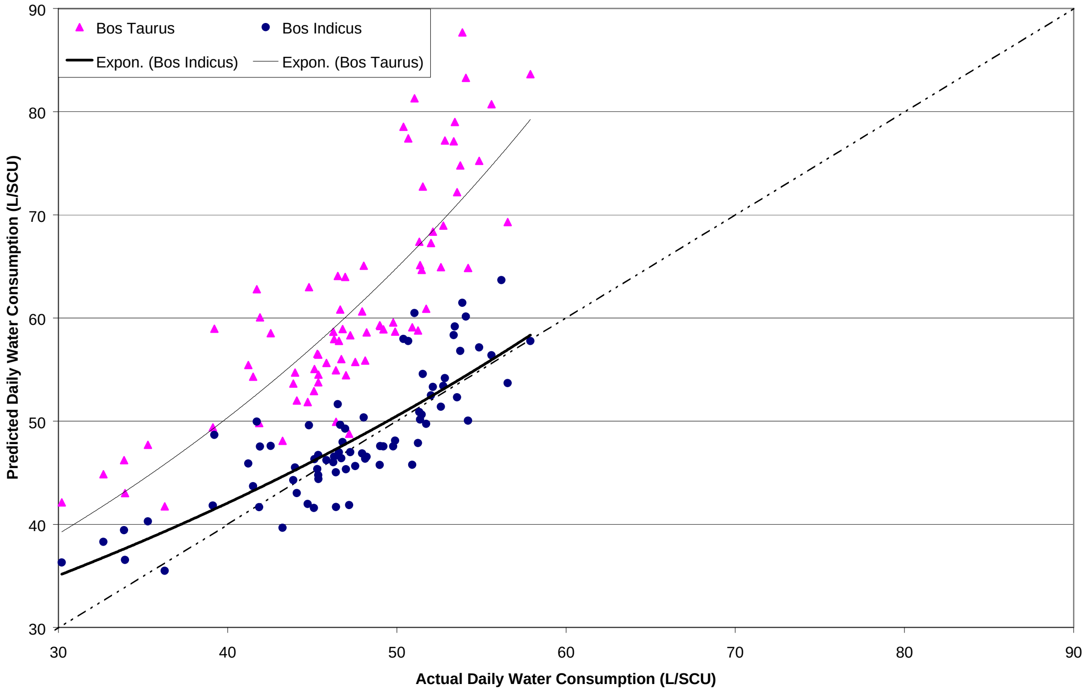


FIGURE 21 - NON-RAIN DAY WATER CONSUMPTION FOR SHADED PENS – WINCHESTER & MORRIS DATA

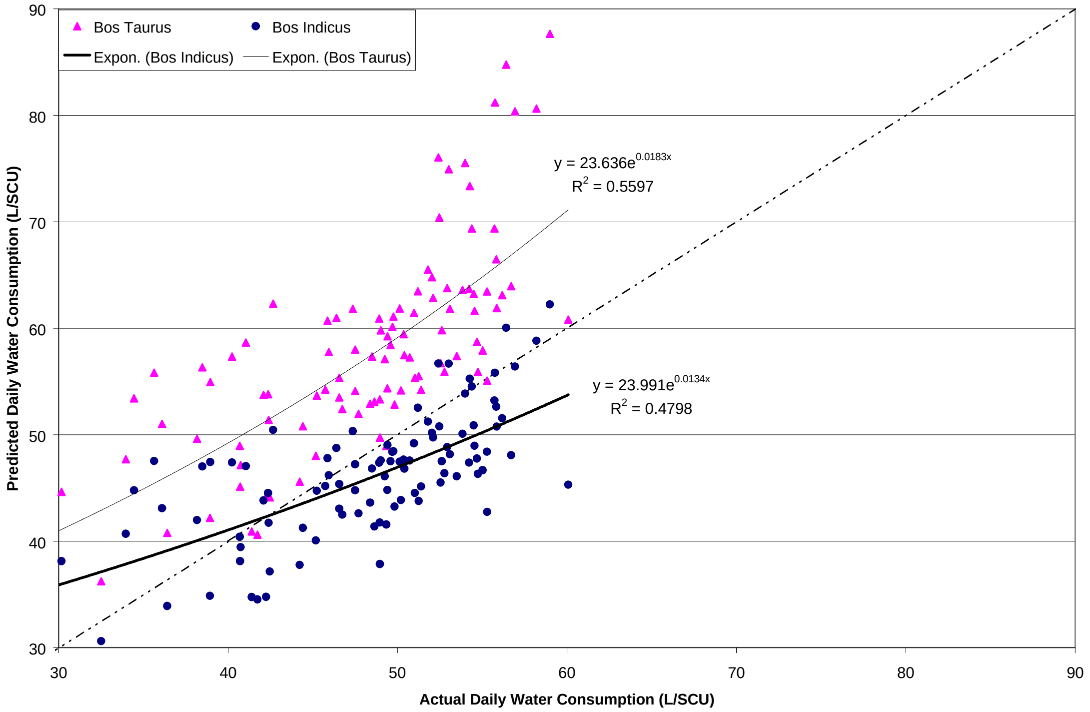


FIGURE 22 - NON-RAIN DAY WATER CONSUMPTION FOR UNSHADED PENS – WINCHESTER & MORRIS DATA

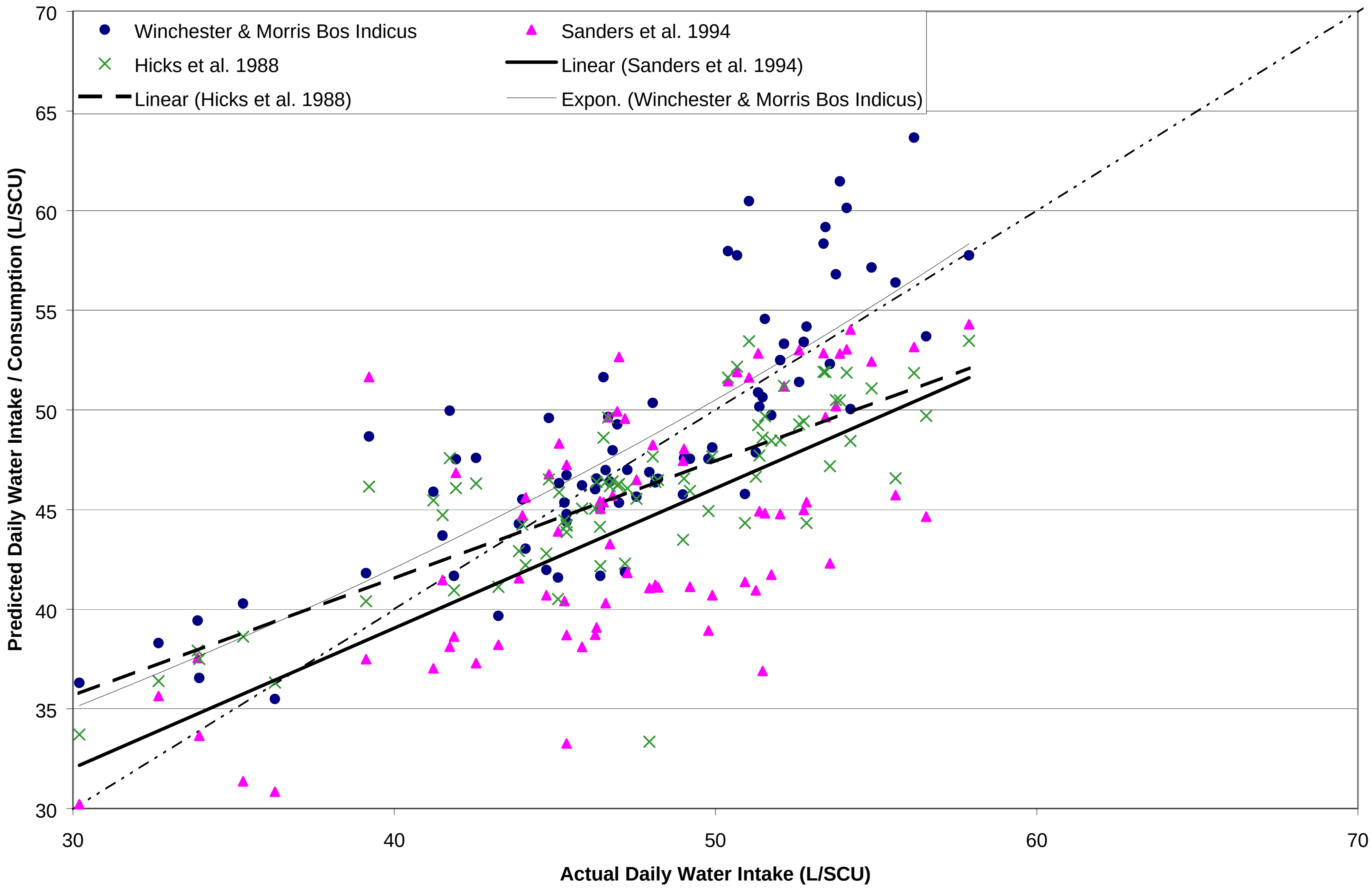


FIGURE 23 - NON-RAIN DAY WATER CONSUMPTION FOR SHADED PENS – PREDICTIVE MODELS

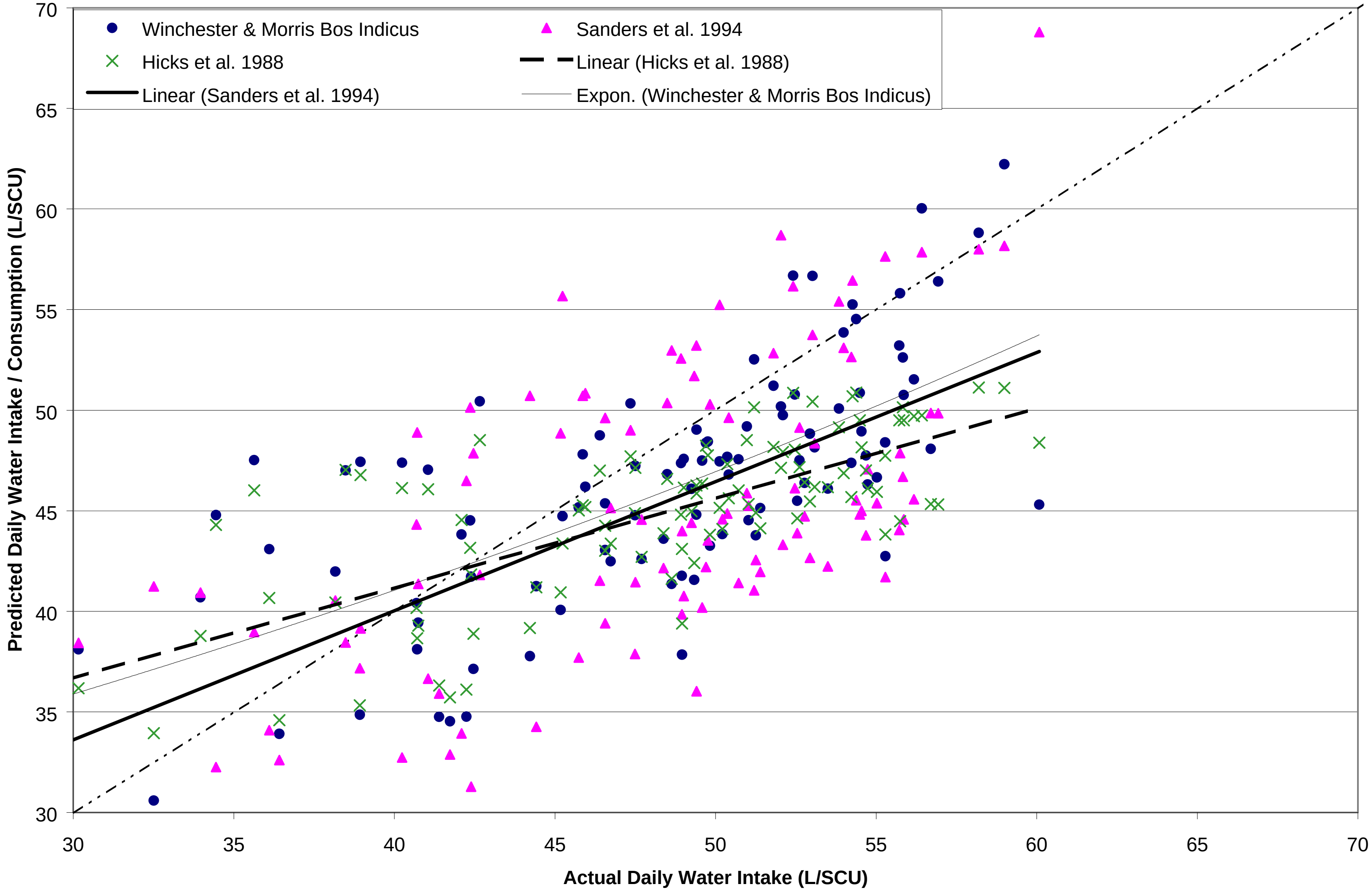


FIGURE 24 - NON-RAIN DAY WATER CONSUMPTION FOR UNSHADED PENS – PREDICTIVE MODELS

7.4.4 Simplified Water Consumption Model

The model proposed by Sanders et al. (1994) has limitations since the climatic parameters used by the model are not always available for a given site. The data was re-examined using commonly available parameters to assess whether a relationship could be developed from the trial data that would provide reasonably accurate results.

Maximum daily ambient temperature is one parameter that is commonly recorded at a wide range of locations. Water consumption data was recorded in six minute intervals, allowing daily totals to be calculated. Cattle numbers and feed intake data were also available on a daily basis. A relationship between maximum daily ambient temperature and recorded daily water consumption per standard cattle unit (SCU) and as a function of daily dry matter intake (DMI) was investigated.

The recorded data for each treatment was averaged for each feedlot to provide shaded and unshaded data for each site. These data sets were then combined to provide a single set of shaded data and a single set of unshaded data covering both feedlots. The simple model was developed for each of the shaded and unshaded pen treatments by fitting a line through the combined data sets.

The combined data sets were initially examined for unusual data points (outliers). Outliers identified in one analysis (e.g. daily water consumption per SCU) were excluded from both analyses. Two situations were observed to result in water consumption data that was substantially different to most data recorded. The first situation was rainfall events, where water consumption was generally well below typical data. The second situation was reduced feed intake rates, where reductions of 20 – 40% in feed intake over 1-2 days typically caused elevated water consumption rates. Investigation of the periods of reduced feed intake suggested that these are often related to climatic conditions such as rainfall or high temperatures. The data recorded for both of these situations is part of typical feedlot operations and thus should ideally be predicted by a model. However, due to the limited number of these points included in the recorded data, neither situation could be reliably included in a simple predictive model.

The recorded data for shaded pens is shown in Figure 27 per SCU and in Figure 25 as a function of daily DMI. Data for rainfall days and days of sudden changes in feed intake are included as separate series. Figure 28 and Figure 26 show the recorded data for unshaded pens.

These figures show trends of increasing water consumption with increasing maximum daily ambient temperature. Water consumption is shown to approximately double as maximum daily ambient temperature doubles from 20 – 40^{O}C. Data from days with rainfall events shows a general trend for increasing water consumption with increasing temperature, but also shows large variation in recorded values. Data from days with sudden reductions in feed intake also show large variation, but no obvious trend.

Whilst trends may have been identified in the data, the study was only conducted over approximately three months in two southern Queensland feedlots, principally during summer. Consequently, the study results relate to a narrow range of climatic conditions. Hence, the limited data set available does not allow any relationship to be confidently developed between daily water consumption and maximum daily temperature. Further work is required to assess whether a simple relationship could be reliably developed to predict daily water consumption.

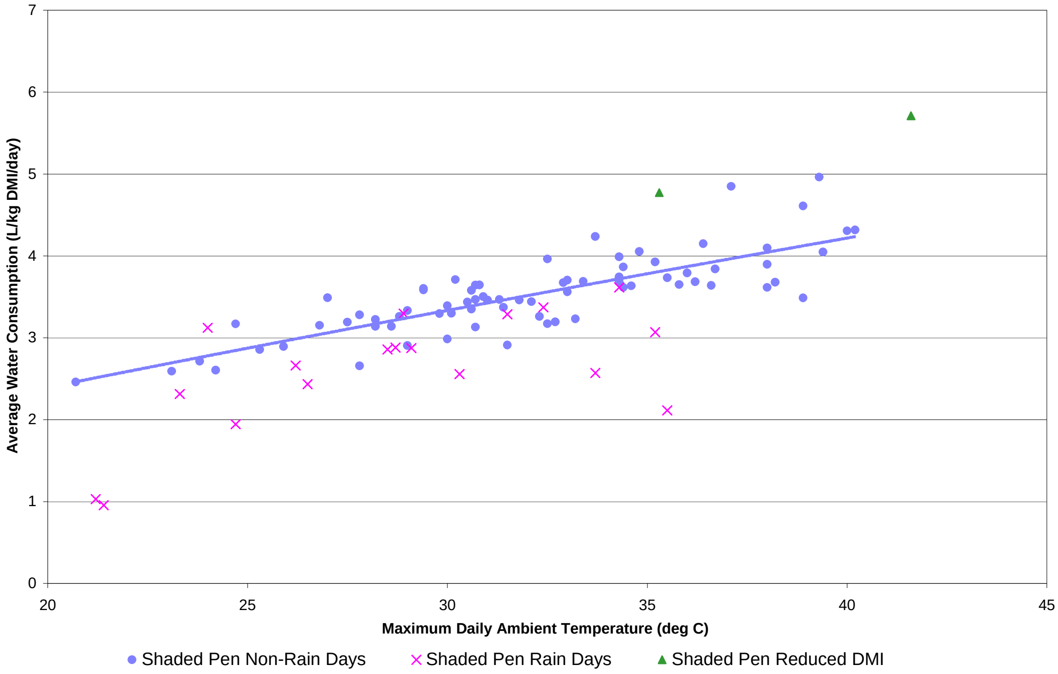


FIGURE 25 - SHADED PEN WATER CONSUMPTION RELATED TO DRY MATTER INTAKE (DMI) AND TEMPERATURE

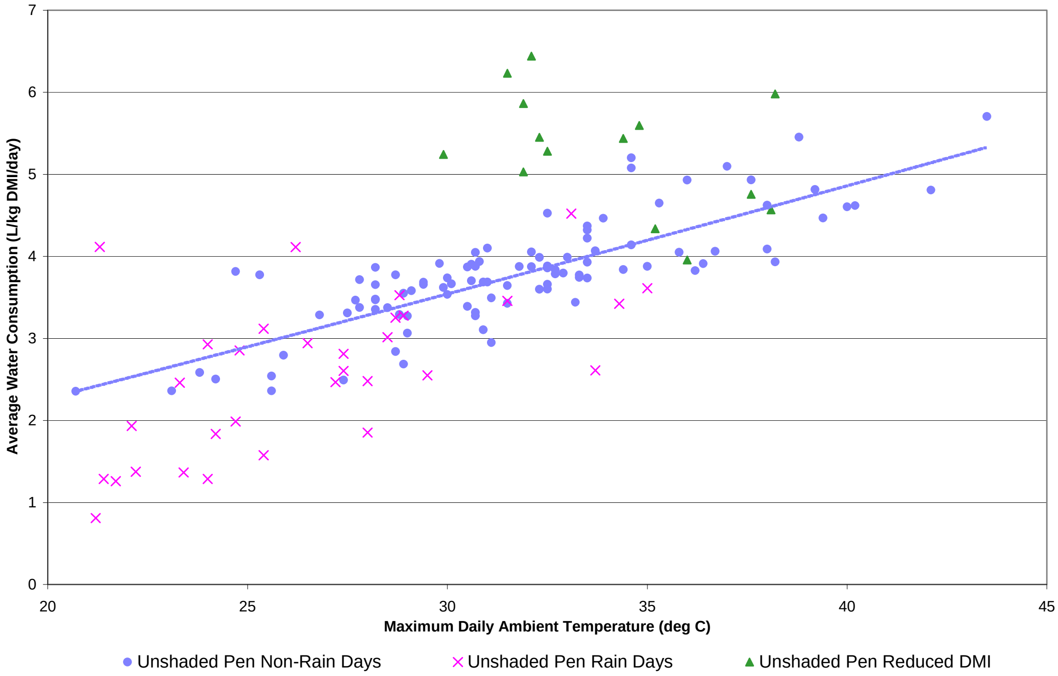


FIGURE 26 - UNSHADED PEN WATER CONSUMPTION RELATED TO DRY MATTER INTAKE (DMI) AND TEMPERATURE

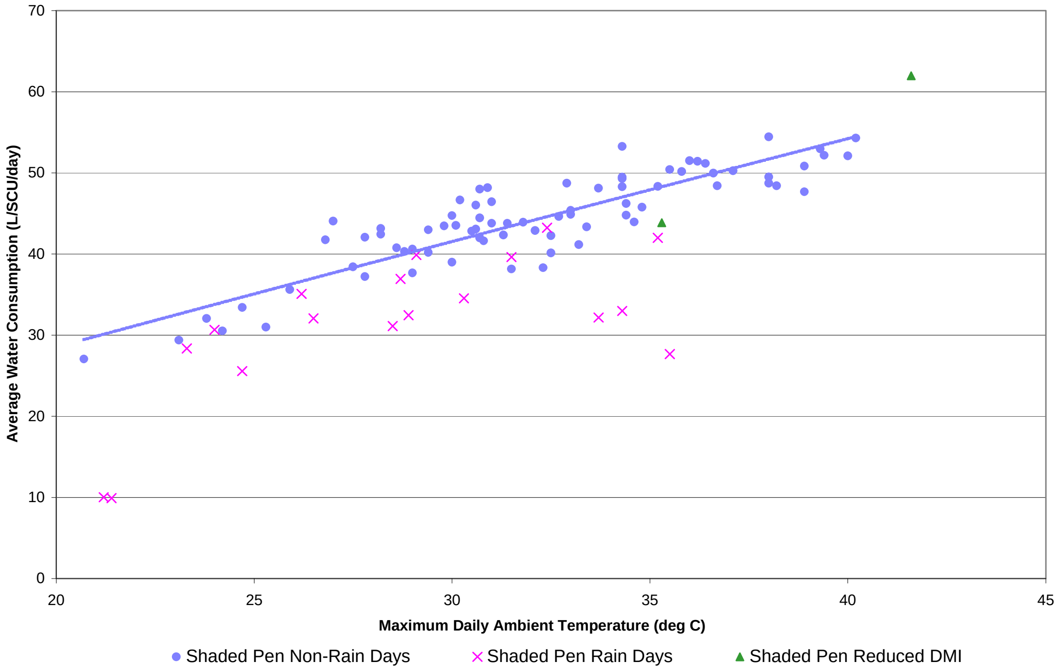


FIGURE 27 - SIMPLE MODEL RELATING MAXIMUM TEMPERATURE TO SCU FOR SHADED PEN DATA

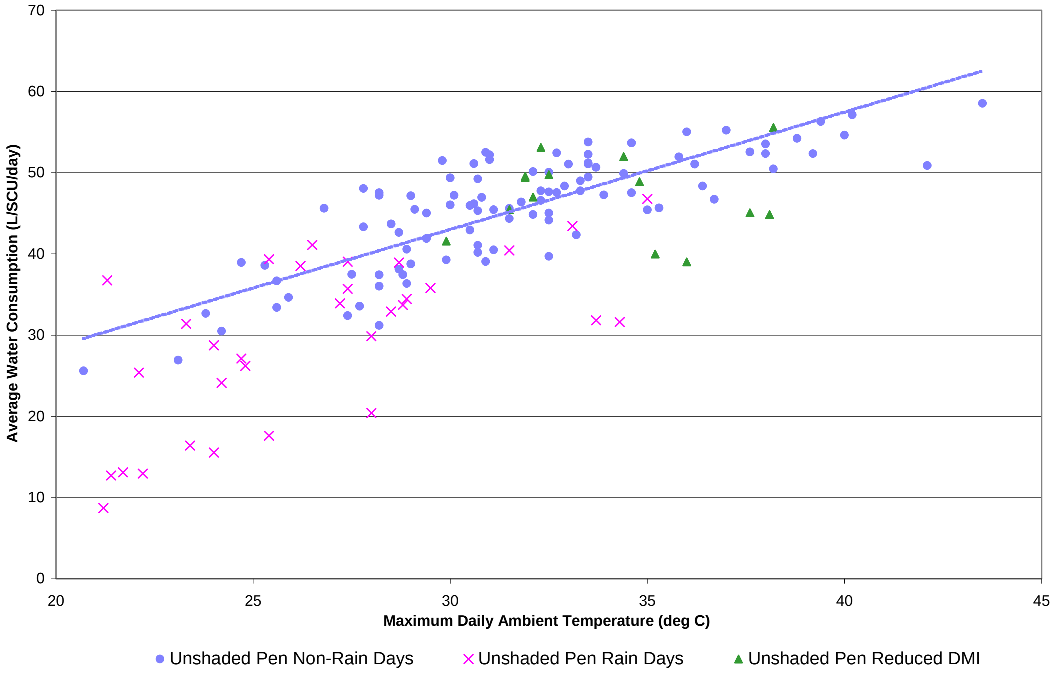


FIGURE 28 - SIMPLE MODEL RELATING MAXIMUM TEMPERATURE TO SCU FOR UNSHADED PEN DATA

8 Conclusions

The pattern of water consumption throughout the day was relatively consistent across all treatments. Water consumption rates generally followed heat load index values, with minimal consumption between midnight and 6 am, peak consumption between 6 am and 8 pm and low consumption between 8 pm and midnight. Water consumption rates were higher during and following periods of high heat load index peak values (>90), with a more pronounced peak consumption period from 2 – 8 pm. Large variations in water consumption between 6-minute recording periods were observed throughout the day for all treatments.

The results of the water consumption trials show that shading, ambient temperature, rainfall and dry matter intake all influence water consumption across feedlots. The results indicate that shading reduces water consumption and generally reduces the length of peak water demand. The results also showed that parameters are inter-related, with climate (temperature and rainfall) influencing feed intake as well as water consumption. Insufficient data was available (limited data points, narrow range of values) to determine how the parameters influenced each other.

Higher maximum daily ambient temperatures (>30°C) were associated with large peak hourly water demands for unshaded pens, while shaded pens under the same temperatures had much lower peak demand. Lower maximum daily ambient temperatures produced larger peaks in hourly water consumption in shaded pens than unshaded pens, but similar peak rates of consumption (i.e. the peak hourly rate of consumption in unshaded pens was closer to the consumption rates throughout the day. The extent of changes in water consumption with a given change in climatic conditions (e.g. an increase in maximum daily ambient temperature of 5°C) was not consistent over time, possibly reflecting the inter-relationships between parameters.

Increases in feed intake resulted in higher water consumption. Cattle tend to consume more feed during the afternoon, leading to generally high afternoon water consumption. High ambient temperatures may depress feed intake, and hence water consumption. However, high ambient temperatures tend to increase water consumption, so the relationship between feed intake and water consumption is not simple.

Water consumption models previously proposed by Sanders et al. (1994 – based on this data set), Hicks et al. (1988), and Watts et al. (1994 – based on results from Winchester and Morris) were compared to measured data and to each other. The analysis showed that the Sanders et al. (1994) and Hicks et al. (1988) models tended to under-estimate water consumption compared to the measured data. The Winchester and Morris model (using the *Bos indicus* data) tended to under-estimate water consumption for ambient temperatures <35°C and over-predict water consumption at higher temperatures. All model results are generally within the range of measured data except for the Winchester and Morris model results for shaded pens.

The data was reviewed to determine if a simple relationship between daily water consumption and environmental factors could be found. The review found trends between daily water consumption and maximum daily temperature, however due to the limited data available no relationship could be confidently developed. The development of a simple model that can provide approximate water consumption estimates for locations where meteorological data is restricted would be of benefit to the Australian Industry.

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Environmental Sustainability Assessment of the Australian Feedlot Industry

Part F Report: Resource Use and Environmental Impact Assessment

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Abstract

The Australian red meat industry, as with most primary industries, is coming under increasing pressure from both the community and government to document and justify its impacts on the environment. This project addresses the public misconceptions of the environmental sustainability of the feedlot industry by providing information on the quantities of nutrients supplied to the feedlot and the fate and quantity of nutrient leaving the feedlot.

MLA is undertaking a project (COMP.094) that will address these issues and provide credible data on the industry's environmental impacts and sustainability for use by industry, including its interactions with government, community groups and the media. This undertaking will utilise the standardised tool, Life Cycle Analysis (LCA), to quantify natural resource consumption and environmental interventions to water, soil and air.

As part of the overall industry project, the beef cattle lotfeeding sector is undertaking a related project that will contribute to the whole of industry dataset, but more importantly addresses the public misconceptions of the environmental sustainability of the feedlot industry.

In the context of the LCA, the feedlot-relevant natural resource management (NRM) issues identified as issues of concern to the feedlot industry were assessed. The largest component of the project was the life cycle inventory (LCI) which enabled the impact assessment to be undertaken. A detailed survey of feedlot inputs and outputs was undertaken using an on-line survey to collect data for the LCI.

A wide range of data was collected with the objective of providing enough information to undertake the impact assessment required.

Executive Summary

The Australian red meat industry, as with most primary industries, is coming under increasing pressure from both the community and government to document and justify its impacts on the environment. Currently, a lack of credible supply chain data prevents the industry from being able to respond in a meaningful manner.

Meat and Livestock Australia (MLA) is undertaking a project (COMP.094) that will address these issues and provide credible data on the industry's environmental impacts and sustainability for use by industry, including its interactions with government, community groups and the media. This undertaking will utilise the standardised tool, Life Cycle Analysis (LCA), to quantify natural resource consumption and environmental interventions to water, soil and air.

LCA is a form of cradle-to-grave system analysis developed for use in manufacturing and processing industries to assess the environmental impacts of products, processes and activities by quantifying their environmental effects throughout the entire life cycle. An LCA is essentially a quantitative study. Sometimes environmental impacts cannot be quantified due to a lack of data or inadequate impact assessment models. Quantitative analysis requires standardised databases of main processes (e.g. energy, transport) and software for managing the study's complexity.

As part of the overall industry project, the beef cattle lotfeeding sector is undertaking a related project that will contribute to the whole of industry dataset, but more importantly addresses the public misconceptions of the environmental sustainability of the feedlot industry. It will identify and quantify the environmental costs associated with the production of one kilogram of grained beef to enable comparison with its domestic competing products (grass fed beef, lamb, pig and poultry meats).

MLA funded a project (FLOT.328) to measure environmental costs associated with the production of one kilogram of meat from modern Australian feedlots. The data is to be used to benchmark the environmental sustainability of the feedlot industry against its domestic and international competitors.

In the context of the LCA, the feedlot-relevant natural resource management (NRM) issues identified as issues of concern to the feedlot industry were assessed. The largest component of the project was the life cycle inventory (LCI) which enabled the impact assessment to be undertaken. A detailed survey of feedlot inputs and outputs was undertaken using an on-line survey to collect data for the LCI.

A wide range of data was collected with the objective of providing enough information to undertake the impact assessment required. The data collected included data on cattle numbers, intake and sale weights, dressing percentages and other parameters that allow red meat production to be estimated for two years (2002 & 2004). Cattle numbers were broken down into each main market type so that later analysis could be used to find if different market types had different environmental impacts.

Data was collected on feed usage data broken down into each major commodity, clean water usage (ML/yr) broken up by volume used for drinking, cattle washing, feed processing, farm/office, shandying effluent for irrigation and clean water irrigation, energy use, staff numbers, manure and

effluent production, usage of chemicals including veterinary, herbicide and pesticide chemicals and environmental performance assessed by the range of environmental management systems implemented at each feedlot.

Data were collected from nine feedlots ranging in size from 1000 head to 25,000 head and geographically spread from Victoria to Queensland.

Feedlots have the potential to affect the quality of surface water bodies and groundwater. The key risks to water quality arise from the nutrients (N,P,K) and salts concentrated in feedlot by-products, although properties like biological oxygen demand (BOD), solids content and heavy metal concentrations could also potentially reduce water quality.

Water is both the most important nutrient for cattle and the most valuable natural resource (after land) in Australia. The Part A Report - ‘Water Usage at Australian Feedlots’ provides data on the quantity of water required to produce red meat within the feedlot sub-system only.

Salinity is a major problem in many agricultural areas in Australia. Salt, previously stored in the landscape is now being mobilised on a massive scale by rising groundwater tables due to land use changes across Australia.

Information to assist feedlot operators to reduce nutrient and sediment delivery to streams by minimising and possibly reversing land degradation has focused on soil and wind erosion control within the feedlot area and sound management of effluent and manure reuse areas.

There appears to be no published information regarding the acidification of soil from application of feedlot effluent or manure in Australia. However, given the experiences in broad-acre agriculture, it is probable that soil acidification could develop at some feedlot sites – probably due to the leaching of nitrate below the root zone. This should be evident in annual soil monitoring results as required by regulatory agencies and should be addressed on an individual site basis. Soil acidification will be addressed in more detail in COMP.094.

Herbicide chemical use in the feedlot and on surrounding farming area was required to be input into the survey. Herbicide use around the feedlot was found to be very limited and a very small proportion of total chemical use, typically less than 5%. Herbicide use is just one way to control weeds, hence these data do not identify the extent of weed problems at feedlots. It is also not surprising that it is a small percentage of total chemical use at a feedlot.

As part of the LCI survey, respondents were asked if feral animals were considered a problem for their business. Feral animals are not a major NRM issue at feedlots and will be discussed in greater detail in the COMP.094 project.

Biodiversity decline is most closely linked to habitat destruction. As the immediate footprint of feedlots is quite small and as most feedlots are built on already cleared sites, the direct biodiversity decline impact of feedlots is quite small. The greater biodiversity decline of feedlots would be indirect such as the production of feed grain, breeding of cattle for use in the feedlot and off-site impacts of nutrient releases to the air and water. These indirect impacts will be discussed in more detail in the COMP.094 project.

Energy is fundamental to a feedlot production system. This project was able to produce quantitative data on energy use and GHG emissions from feedlots. The FLOT.328 Final report Part B - ‘Energy Usage and GHG Emissions at Australian Feedlots’ - provides a comprehensive account of the energy usage and GHG emissions at Australian feedlots.

In conventional LCA, solid waste refers to the wastes that must be disposed of in landfills. For feedlots this would include regulated and non-regulated wastes. Regulated wastes from feedlots would include old tyres, spent oil and chemical containers. Unregulated waste would include office materials (waste paper, etc) and general packaging.

Most feedlots responding to the survey did not have good records of solid waste disposal. However, the data supplied indicated that the amounts were very small when expressed on a per kg HSCW basis. Many feedlots recycle solid wastes (old tyres, spent oil, waste paper). Factual information on the quantity of solid organic waste produced is provided in the FLOT.328 Final report Part C – ‘Nutrient Cycling at Australian Feedlots’.

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1 Background

The Australian red meat industry, as with most primary industries, is coming under increasing pressure from both the community and government to document and justify its impacts on the environment and its use of natural resources. This is evident through the government emphasis on industry initiatives such as the implementation of Environmental Management Systems (EMS) and Triple Bottom Line (TBL) reporting requirements. Currently, a lack of credible supply chain data prevents the industry from being able to respond in a meaningful manner.

Meat and Livestock Australia (MLA) is undertaking a project (COMP.094) that will address these issues and provide credible data on the industry's environmental impacts and sustainability for use by industry, including its interactions with government, community groups and the media. This project will utilise the standardised tool, Life Cycle Assessment (LCA), to quantify natural resource consumption and environmental interventions to water, soil and air.

A separate but related project (FLOT.328) is being undertaken for the lot-feeding sector of the Australian red meat industry.

1.1 Project Description

As part of the overall industry project, the beef cattle lot feeding sector is undertaking a related project (FLOT.328) that will contribute to the whole of industry dataset, but more importantly will address the public misconceptions of the environmental sustainability of the feedlot industry by identifying and quantifying the environmental costs associated with the production of one kilogram of grained beef to enable comparison with its domestic competing products (grass fed beef, lamb, pig and poultry meats).

Given that environmental sustainability will eventually become a key element in maintaining and improving access for Australian product into key overseas markets, it is envisaged that the project will also benchmark these costs against international competitors (US and European beef) and identify areas of R&D investment to ensure the long-term viability and sustainability of the feedlot production system.

2 Project Objectives

The FLOT.328 project will:

1. Collect, collate and present relevant data to enable MLA to assess/benchmark the environmental sustainability of the feedlot industry against its domestic and international competitors by assessing the environmental costs associated with the production of one kilogram of meat from each production system
2. Provide data for the feedlot industry suitable for use within the broader red meat supply chain Life Cycle Assessment (COMP.094)
3. Identify areas for potential future R&D investment to ensure long-term competitiveness, viability and sustainability of the feedlot production system; and
4. Communicate the results of the assessment to MLA in a format suitable for dissemination to industry stakeholders.

This report provides a summary of feedlot-relevant natural resources management issues (NRM), data collection and results. A discussion of the environmental impact of the use of these resources by beef cattle feedlots is also included.

3 Life Cycle Assessment

MLA is undertaking a project (COMP.094) that will provide credible data on the red meat industry's environmental impacts and sustainability for use by industry, including its interactions with government, community groups and the media. This project will utilise the standardised tool, Life Cycle Assessment (LCA), to quantify natural resource consumption and environmental interventions to water, soil and air. This project (FLOT.328) is being undertaken for the lot feeding sector of the Australian red meat industry. The following description of LCA is taken from Peters et al. (2005).

3.1 Description of LCA

LCA is a form of cradle-to-grave systems analysis developed for use in manufacturing and processing industries to assess the environmental impacts of products, processes and activities by quantifying their environmental effects throughout the entire life cycle. LCA can be used to compare alternative products, processes or services; to compare alternative life cycles for a product or service; and to identify those parts of the life cycle where the greatest improvements can be made. An international standard has now been developed to specify the general framework, principles and requirements for conducting and reporting LCA studies (Standards Australia 1998). LCA differs from other environmental tools (e.g. risk assessment, environmental performance evaluation, environmental auditing, and environmental impact assessment) in a number of significant ways. In LCA, the environmental impact of a product or the function a product is designed to perform is assessed, the data obtained are independent of any ideology and it is much more complex than other environmental tools. As a systems analysis, it surpasses the purely local effects of a decision and indicates the overall effects.

There are four aspects of life cycle assessment (see Figure 1):

- *Goal and Scope Definition* defines the goal, functional unit and associated system to be studied.
- *Inventory Analysis* analyses all process inputs and outputs. It involves modelling unit processes in the system, considered as inputs from the environment (resources and energy) and outputs (product, emissions and waste) to the environment. Allocation of inputs and outputs needs to be clarified where processes have several functions (for example, where one production plant produces several products). In this case, different process inputs and outputs are attributed to the different goods and services produced. An extra simplification used by LCA is that processes are generally described without regard to their specific location and time of operation.
- *Impact Assessment* makes results from the inventory analysis more manageable and understandable in relation to natural environment, human health and resource availability.
- *Interpretation* involves evaluating inventory analysis and impact assessment outcomes against the study's goal.

An LCA is essentially a quantitative study. Sometimes environmental impacts cannot be quantified due to a lack of data or inadequate impact assessment models. A guide to decisions can then be qualitative use of LCA and use of other tools for supply chain analysis. Quantitative analysis requires standardised databases of main processes (energy, transport) and software for managing the study's complexity.

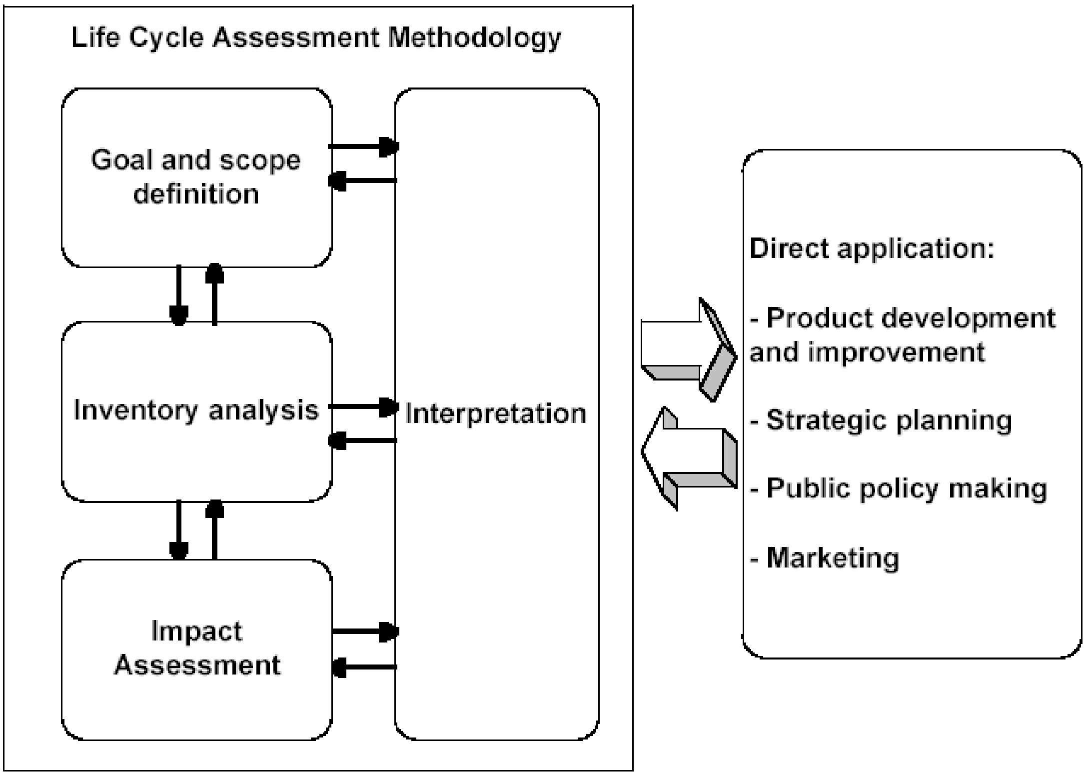


FIGURE 1 – GENERAL FRAMEWORK FOR LCA AND ITS APPLICATION (STANDARDS AUSTRALIA 1998)

3.2 Selection of Functional Unit

The functional unit for this study is the delivery of one kilogram of hot standard carcass weight (HSCW) meat at the abattoir. AUS-MEAT is the authority for uniform specifications for meat and livestock in Australia. In March 1987, they introduced the term HSCW as a national standard. The HSCW is the fundamental unit of “over the hooks” selling and is the weight, within two hours of slaughter, of a carcass with standard trim (all fats out). This is a carcass after bleeding, skinning, removal of all internal organs, minimum trimming and removal of head, feet, tail and other items (AUS-MEAT 2001). “Hot” indicates that the meat in question has not entered any chilling operations. This output-related functional unit was chosen, rather than an input-related one, in order to describe the human utility of the processes under consideration – the provision of nutrition for people. Although the meat could be served in different ways, this functional unit makes the different processes under consideration “functionally equivalent” from a dietary perspective.

3.3 System Boundaries

In LCA methodology, usually all inputs and outputs from the system are based on the ‘cradle-to-grave’ approach. This means that inputs into the system should be flows from the environment without any transformation from humans and outputs should be discarded to the environment without subsequent human transformation (Standards Australia, 1998). Each system considers upstream processes with regard to the extraction of raw materials and the manufacturing of products being used in the system and it considers downstream processes as well as all final emissions to the environment. Figure 2 shows the generalised system boundary for the red-meat sector as defined for the COMP.094 project. Within this boundary, there is a sub-system for the feedlot sector. The boundary chosen here (shown in red on Figure 2) is the feedlot site itself plus the transport component of bringing cattle and feed into the feedlot and delivering cattle from the feedlot. This is also shown with more detail in Figure 3. The production of feed for the feedlot will be examined in a larger system analysis.

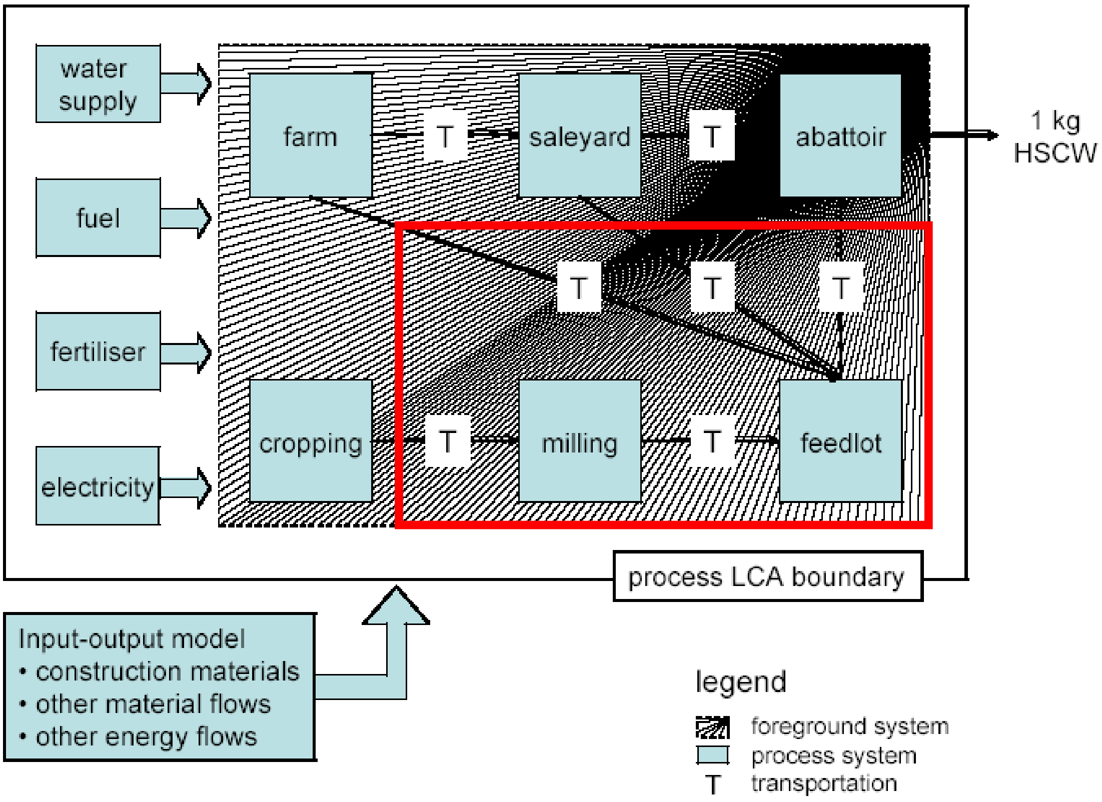


FIGURE 2 – GENERALISED SYSTEM MODEL FOR THE RED MEAT SECTOR WITH FEEDLOT SUB-SYSTEM

3.4 Life Cycle Inventory (LCI)

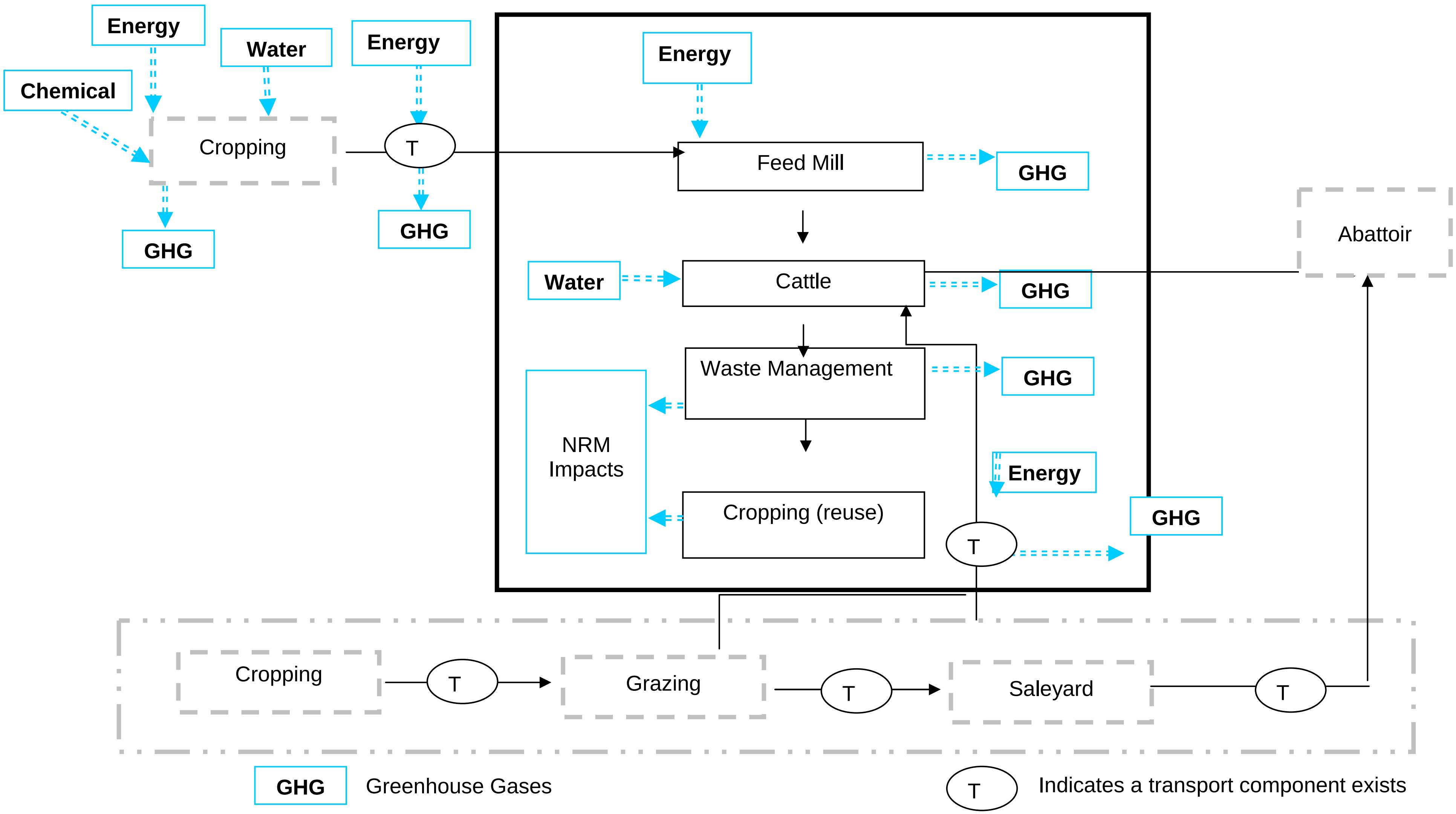
Inventory analysis is the second phase in a life cycle assessment and is concerned with data collection and calculation procedures. The Inventory Analysis phase forms the body of the LCA as the majority of time and effort in an LCA is spent on Inventory Analysis. As a rule of thumb, 80 percent of the time required for an LCA is needed for this phase. The operational steps in preparing a life cycle inventory (LCI) are according to ISO 14041 (Standards Australia, 1999):

- data collection.
- relating data to unit processes and/or functional unit.
- data aggregation.

- refining the system boundaries.

This report provides a summary of feedlot-relevant NRM issues and a discussion of the environmental impact of the use of these resources by the feedlot sub-system.

FIGURE 3 – PROJECT BOUNDARY – FEEDLOT SYSTEM



4 Project Methodology & Reporting

4.1 Terms of Reference Requirements

Across a diverse range of industry sectors there is a persistent trend towards the use of life cycle based approaches to environmental management and consideration of sustainability issues.

The goal of the LCA is to identify key environmental impacts of products. Environmental impact categories considered in LCA include but are not limited to resource energy, climate change (global warming), eutrophication, acidification, human toxicity (pesticide use) and land use.

The Terms of Reference for this project required the researchers to address, in the context of a LCA, the feedlot-relevant natural resource management (NRM) issues from the following list, identified as issues of concern to the red meat industry:

- Water quality and water use efficiency.
- Salinity.
- Soil erosion.
- Nutrient management and soil acidification.
- Weeds.
- Feral animals.
- Biodiversity.
- Vegetation management.
- Energy efficiency and greenhouse gas emissions.
- Solid waste.

These are the same NRM issues to be addressed in the COMP.094 project. The COMP.094 project has a longer time frame than FLOT.328 and has not yet addressed these issues for the grazing sector. Data from FLOT.328 will be essential input to COMP.094. No financial data was to be collected as part of this project.

To allow the incorporation of these NRM issues into an LCA, they need to be quantified by their environmental impacts and by a causal link to the red-meat industry. The inclusion of NRM environmental indicators into LCA is at a very developmental stage with limited studies having included them in a meaningful way and or in a way that is relevant to Australian conditions. A challenge to these MLA projects is how to incorporate NRM issues into traditional LCA approaches.

4.2 Project Proposal Methodology

In the Project Proposal for FLOT.328, it was noted that the development of quantitative indicators for many NRM issues is at various stages of development with many catchment authorities across Australia trying to develop meaningful NRM monitoring data. Hence, for most of the nominated NRM issues, only a qualitative assessment is possible for this project (given a limited timeframe and budget). The project team proposed to approach the project as an opportunity to explore existing data and methodologies with the aim of working out how LCA can be applied to the Australian feedlot industry and identifying areas of future research to further assist this application.

Some NRM issues such as soil erosion, feral animals, biodiversity and vegetation management are of greater concern to the grazing industry than the lot feeding sector. The exact manner in which these issues will be addressed in LCA is still under debate. Hence, the conclusions drawn in this report may be revised when COMP.094 is finalised. A preliminary summary of these impacts as they apply to the feedlot industry is presented in Table 1. Step 3 of the Project Proposal proposed to use information from Step 2 (LCI – see below) to discuss the NRM issues as they apply to the Australian feedlot industry.

4.3 Life Cycle Inventory (LCI) Survey

The largest component of this project was the life cycle inventory (LCI) which enabled the impact assessment to be undertaken.

The original project proposal envisaged that the LCI would involve a detailed survey of feedlot inputs and outputs. This survey was discussed at the first Steering Committee Meeting and it was resolved that the survey should be undertaken on-line. The aim was to reduce the need for researchers to travel to feedlots to undertake surveys and to allow the feedlot managers to enter data at their convenience. The original hard copy survey form was edited and then uploaded as an on-line survey. Milestone Report No. 2 shows the survey form (Watts 2006). Before wider release, the survey form was beta-tested using members of the Steering Committee who provided feedback on its usability and on whether the requested data could be readily obtained.

TABLE 1 – PRELIMINARY SUMMARY OF NRM ISSUES AS THEY APPLY TO THE FEEDLOT INDUSTRY

NRM Issues	How issue relates to feedlots	How the issue will be addressed
Water quality	Soil erosion (N, P, K) from cropping to produce feed and effluent reuse sites. Effluent releases from feedlots, through pond spills and runoff of irrigated effluent.	Quantitative broad estimate, indirect measure
Water use efficiency	Water use/kg HSCW gain	Quantitative, broad estimate
Salinity	Effluent reuse	Available data examined, knowledge gaps identified
Soil erosion	Soil erosion (N, P, K) from site	Quantitative – broad estimate.
Nutrient management	Effluent reuse	Quantitative – broad estimate
Soil acidification	Effluent reuse and production of feed grain	Review available data. Identify knowledge gaps.
Weeds	Effluent reuse and production of feed grain	Review available data. Identify knowledge gaps.
Feral animals	Feedmill Carcass management	Review available data. Identify knowledge gaps.
Biodiversity	Production of feed grain	Review available data. Identify knowledge gaps.
Vegetation management	Production of feed grain	Review available data. Identify knowledge gaps.
Energy efficiency & GHG emissions	Energy use / kg HSCW gain GHG emissions / kg HSCW gain	Quantitative
Solid Waste	Solid waste/kg HSCW gain	Quantitative

One problem encountered during the beta-testing phase was the lack of clear definitions for feedlot terms. Even such terms as stocking density, occupancy (utilisation) and mortality rates were interpreted differently amongst feedlot managers. A large number of “Help” windows were uploaded to the survey site so that guidance could be obtained when inputting data under different sections.

It was decided to collect data for two calendar years, being 2002 and 2004. The intent was to have data from two years of differing climatic conditions viz drought v good year. Differing climatic conditions impact on feedlot occupancy and resource use (e.g. water and feed intake). While it would have been desirable to find two years of more dramatic difference, it was concluded that it was unlikely that good quality data could be obtained if the survey period was more than a few years ago.

A wide range of data was collected with the objective of providing enough information to undertake the impact assessment required. The data collected included the following:

1. Data on cattle numbers, intake and sale weights, dressing percentages and other parameters that allow red meat production to be estimated for two years (2002 & 2004). This data could be analysed to determine the tonnage of HSCW gain in the feedlot over a 12-

month period. Cattle numbers were broken down into each main market type so that later analysis could be used to find if different market types had different environmental impacts.

2. Feed usage data broken down into each major commodity.
3. Clean water usage (ML/yr) broken up by volume used for drinking, cattle washing, feed processing, farm/office, shandying effluent for irrigation and clean water irrigation.
4. Energy usage broken down into energy type (diesel, electricity, gas, etc.) and area of usage.
5. Estimates of haulage distances from cattle into and out of the feedlot and for feed commodities into the feedlot.
6. Staff numbers.
7. Manure and effluent production.
8. Usage of chemicals including veterinary, herbicide and pesticide chemicals.
9. Environmental performance assessed by the range of environmental management systems implemented at each feedlot.

Data were collected from nine feedlots ranging in size from 1000 head to 25,000 head and geographically spread from Victoria to Queensland.

4.4 LCI Data Analysis and Interpretation

Once the data inventory is completed, the next step in LCA is interpretation. This results in the expression of impacts per functional unit of output (functional unit). In this case, it would be litres of water consumed to produce 1 kg of HSCW (L/kg HSCW) or greenhouse gas emission per kilogram of HSCW produced (t CO_2-e/kg HSCW). This requires data analysis to normalise the resource usage and environmental output data to functional unit basis.

In addition, the terms of reference for the project required that the analysis address the geographical, climatic and feeding regime diversity within the beef cattle feedlot sector. It is envisaged that the following four (4) feeding x market destination categories will be evaluated:

- 60-70 day fed domestic market.
- 100-120 day fed export market.
- 120-200 day fed export market.
- 200+ day fed export market.

To undertake the required analysis, a large Feedlot System Analysis Model spreadsheet (FSA Model) was developed. The model was based initially on the DPI&F BEEFBAL model but was expanded to include energy usage, greenhouse gas emissions, water usage and National Pollution Inventory (NPI) calculations. The spreadsheet was designed to accept as input data collected from the on-line survey. The spreadsheet was designed so that, after analysis of survey results from specific feedlots was undertaken, generic feedlots in different geographical zones and with different feeding regimes could be analysed on a comparative basis.

After data was entered into the survey by the lot feeders, the data was entered into the FSA Model where various parameters were calculated and data quality checks were undertaken. Where anomalous data was detected, the participating feedlot was contacted and the data examined in more detail. However, in some cases there still remained a mismatch between the mean number of cattle on hand estimated by the FSA model and that given in the survey. In most cases this was due to the yearly cattle number data and summary mean cattle on hand entered into the survey which does not capture monthly fluctuations.

4.5 Project Reporting Structure

This project includes the LCI collection and analysis of a large quantity of data from operational feedlots on the environmental costs associated with the production of one kilogram of hot standard carcass weight gain (HSCW gain). In this context, HSCW gain is the difference between total dressed carcass weight of cattle leaving the feedlot less the estimated total dressed carcass weight of cattle entering the feedlot. To ensure that this data and information is presented in a suitable manner, six reports have been compiled.

A. Water Usage at Australian Feedlots. This report presents a background literature review of water usage at feedlots, data collection and results, as well as an analysis and discussion of the data collected. This report is the life cycle inventory for the water use component of the feedlot sub-system.

B. Energy Usage and Greenhouse Gas Emission Estimation at Australian Feedlots. This report presents a background literature review of energy usage and GHG emissions at feedlots, data collection and results. A discussion of results and the relative merits of the current GHG emission calculation methodology by the Australian Greenhouse office (AGO) are included. This report is the life cycle inventory for the energy use and GHG emissions component of the feedlot sub-system.

C. Nutrient Cycling at Australian Feedlots. This report includes a literature review of nutrient pathways at feedlots, data collection and results as well as an analysis and discussion of the data collected. This report is the life cycle inventory for the nutrient cycling component of the feedlot sub-system.

D. NPI Listed Substances Emission Estimation for Australian Feedlots. This report provides a summary of the National Pollutant Inventory (NPI) reporting framework, data collection and results for category I listed substances. The report also includes a discussion of the relative merits of the current NPI emission estimation methodology, with guidance on an alternative method for use under Australian conditions.

E. Review of Lot Fed Cattle Water Consumption – MRC Project No. DAQ.079. This report provides a review of research undertaken in the early 1990’s on water consumption in feedlots. It provides a more detailed literature review on the factors influencing drinking water requirements than is provided in Part A, experimental methodology, data collected and discussion of the results and outcomes of this MRC research.

F. Resource Use and Environmental Impact Assessment for Australian Feedlots. This report provides a summary of feedlot-relevant natural resources management issues (NRM), data collection and results. A discussion of the environmental impact of the use of these resources by beef cattle feedlots is also included.

4.6 Unreported Data

In addition to the data presented in the six reports listed above, the LCI collected some data that is, as yet, unreported. This includes data on chemical use, staff numbers and farm details. This data may yet be used in the COMP.094 project when a clearer understanding of the LCA for the red-meat industry is developed. For example, chemical usage could be used to determine a human toxicity LCA parameter for the red-meat industry.

The data on feed intakes and diet ingredients has not been fully reported in the above reports – although it is used indirectly in the energy and nutrient reports. However, this data is essential to the full LCA for the red-meat industry where the LCA parameters for feed production (cropping in Figure 2 and Figure 3) are a component of the whole supply chain.

All of the data collected will be made readily available to the COMP.094 project when the need arises.

5 Natural Resource Management Issues

5.1 Introduction

The basic function of a feedlot is to provide suitable accommodation, feed, water and care to cattle so that they can grow optimally. The components of a feedlot include:

- Pens, feed alleys, drains, cattle handling facilities and manure storage and treatment area. These essential components are normally confined within a controlled drainage area.
- Effluent storage ponds (collecting runoff from the controlled drainage area – see Photograph 1).
- Feed storage and / or processing area.
- Offices, staff facilities, machinery workshops.
- An effluent reuse (irrigation) area. This is optional and is not required if effluent disposal is by evaporation.
- A manure reuse area. This is optional and is not required if manure can be sent off-farm.
- A buffer area around the feedlot to provide a visual screen and to provide adequate separation between the feedlot and sensitive receptors. This may or may not be on-farm.

Like all farming activities, feedlots have the potential to cause environmental harm and damage to natural resources. However, the risk of this occurring can be minimised through good siting and the use of good design and management processes throughout the feedlot system. Guidance on these areas is readily available through regulatory agencies / state agriculture departments and publications such as Designing Better Feedlots (Watts and Tucker 1994), Queensland Reference Manual (Skerman 2000) and the NSW Feedlot Manual (NSW Agriculture 1997). Strict regulatory processes in most States ensure that all NRM issues are addressed in detail in the planning phase and plans are in place to ensure that the NRM impact is low. This is usually supported by ongoing environmental monitoring required by the regulatory agencies.

The lot-feeding sector also has its own comprehensive quality assurance scheme. The National Feedlot Accreditation Scheme (NFAS) is an industry self-regulatory quality assurance scheme that was initiated by ALFA and is managed by an industry Committee the Feedlot Industry Accreditation Committee (FLIAC). The objective of the NFAS is to develop a Quality System for beef feedlots that impacts positively on product quality and acceptability and for which the lot feeders maintain responsibility. The mission of the NFAS is to ensure the Australian beef feedlot industry develops a responsible feedlot management program to:

- Enhance the marketing prospects for grain fed beef by raising the integrity and quality of the product.
- Establish a viable mechanism for industry self-regulation.
- Improve the image of feedlots held by the community, particularly relating to environment and animal welfare matters.

(Source: www.ausmeat.com.au/programmes/nfas/)

PHOTOGRAPH 1 – AERIAL VIEW OF FEEDLOT

(Note that all runoff from the feedlot area is captured in a series of holding ponds for later disposal by evaporation and / or irrigation).

5.2 The Footprint of the Lot feeding Sector

To put the NRM impact of feedlots in context, it is worthwhile to examine the physical footprint of cattle feedlots in Australia compared to other agricultural industries.

Typically, the stocking density of cattle feedlots is 15 m^2/head. The total catchment area (footprint) of the cattle pens, feed alleys, drains, manure stockpiles, cattle handling facilities and pond systems (see Photograph 1) is 2-3 times the pen area. At present, the total pen capacity of feedlots in Australia is about 1,100,000 head. Hence, the total pen area is about 1650 ha and assuming a conservative three times factor, the total footprint of the main feedlot facilities is 4950 ha – say 5000 ha or 50 km^2. Most feedlots in Australia are located within the Murray-Darling catchment which has a total area of 1,060,000 km^2. Within this catchment, other land uses include 30.9 million ha for beef grazing, 1.6 million ha for dairying, 45.1 million ha for sheep grazing and 11 million ha for cropping including 1.9 million ha of irrigated cropping (Murray Darling Basin eResources 2005). Hence, the footprint of the main feedlot facilities is trivial in area compared to other agricultural industries. However, in many cases feedlots have an associated farming area that is many times greater than the feedlot area. In these cases, apart from the effluent reuse areas, most of the remaining farming area is used in a similar way to surrounding farms and has a similar NRM impact.

5.3 Water Quality

Feedlots have the potential to affect the quality of surface water bodies and groundwater. The key risks to water quality arise from the nutrients (N,P,K) and salts concentrated in feedlot by-products, although properties like biological oxygen demand (BOD), solids content and heavy metal concentrations could also potentially reduce water quality.

The impact on water quality of nutrients and salts in feedlot by-products depends on the quantity of these that enters the water and the extent to which the concentration of nutrients and salts in the water changes. The nutrients with the most potential to cause impacts are typically nitrogen (N), phosphorus (P) and potassium (K).

N in the nitrate form is extremely mobile and readily leached through soil profiles. Elevated nitrate levels in surface waters (>3 mg/L) with elevated P levels, may also lead to eutrophication. The result of this is excessive algal growth, depleted oxygen levels and the possible death of fish and other aquatic organisms.

P is an essential plant nutrient. However attention in recent years has been diverted to the role of P in environmental water pollution. Skerman (2000) states that soil erosion and dissolution of soluble P in run-off water are the main export paths. Thus, there is a need to minimise the loss of N and P from the soil, where they are beneficial, to groundwater and streams where they are harmful.

Salt may enter water bodies through direct contamination with effluent / manure or it may be carried into the water on soil / manure particles eroded by wind or water. The effect of salt on water bodies depends on the pre-existing quality of the water and the change in the salinity of the affected water. The greater the increase in water salinity, the more restricted the potential end-uses of the water, (e.g. consumption by humans / animals, or application to plants). Feedlot design and management should prevent changes to the suitability of water quality for any purpose.

The potential mechanisms of degradation of water quality resulting from a feedlot include:

1. Escape of contaminated runoff from the feedlot pens directly to a watercourse. It is a regulatory requirement of all large feedlots that runoff is contained within a controlled drainage area and that all this runoff is diverted to a holding pond. In some cases, regulatory agencies license small feedlots (<500 head) to operate without a holding pond but this is only in circumstances where the distance to a watercourse is large and the likelihood of runoff reaching the watercourse is low.
2. Holding Pond Discharges. Discharges from a holding pond could enter a watercourse causing a decline in water quality. Holding pond effluent is typically high strength with about 400 mg N/L (range 100-1000 mg N/L), 80 mg P/L (range 30-400 mg P/L) and 5000 mg/L of total salts (range 1000-10,000 mg/L). Discharges could occur due to structural failure of a holding pond embankment or overflow following a large storm event. The regulatory system should ensure that holding ponds are designed and managed such that overflow events occur at an acceptable frequency – say a 1 in 20 year frequency.

3. Runoff from an effluent or manure reuse area. It is possible that rainfall runoff from a reuse area could carry significant quantities of nutrients and salt to a watercourse. This is usually addressed in the planning phase by providing either terminal ponds to collect the first-flush of runoff from the reuse area and/or by providing adequate vegetative buffers between the reuse area and the watercourse.
4. Direct runoff from an effluent irrigation area during irrigation. Over-irrigating effluent can produce direct runoff of effluent during an irrigation event. This is a management issue only and can easily be addressed with suitable irrigation practices.
5. Soil erosion from an effluent or manure reuse area. Eroded soil from a reuse area could carry high levels of nutrients, particularly P. Soil erosion can be controlled with physical works (contour banks, waterways) and with management practices (conservation tillage, etc.)
6. Leaching to groundwater below the feedlot pen area. Research in the USA has established that little water leaches below feedlot pens due to the formation of the impermeable manure interface layer. In recent years, other environmental pressures have led many Australian lot feeders to remove the interface layer during pen cleaning. Hence, it has been necessary to rely on the low permeability of the compacted gravel base of the pens to limit seepage and thus movement of nutrients to groundwater.
7. Leaching to groundwater below holding ponds. Feedlot effluent holding ponds must be designed and built to have a low permeability. This is typically 0.1 mm/day.
8. Leaching to groundwater below reuse areas. It is possible that excess nutrients and salt applied to effluent and manure reuse areas could leach into groundwater. During the planning phase, most feedlots are required to undertake nutrient budgets to demonstrate that the nutrient application rates proposed are sustainable. In the operational phase, on-going good management and regular monitoring should ensure that little leaching of nutrients occurs.

In summary, there are several possible mechanisms for nutrient and salt escape from a feedlot to surface waters or groundwater. However, good planning, design, ongoing good operational practice and regular monitoring should minimise this risk.

Nutrient loss would be episodic related to rainfall events. Hence, a hydrological simulation model such as MEDLI (Gardner et al. 1996) could be used to model nutrient loss events. This modelling could be supported with nutrient balance data from the FLOT.328 Final Report Part C – ‘Nutrient Cycling at Australian Feedlots’.

Water quality issues, including eutrophication of watercourses, will be addressed further in the COMP.094 project.

5.4 Water Use Efficiency

Water is both the most important nutrient for cattle and the most valuable natural resource (after land) in Australia. Hence, it is of critical importance to lot feeders. There is a perception in the popular press that red meat production requires large quantities of fresh water. For example, it is often stated that it takes 50,000 L of water to produce 1 kg of beef. In fact, Gold (2004) claims that it takes 100,000 L to produce 1 kg of beef. However, in Australia, there are few facts to back up these claims.

The Part A Report - ‘Water Usage at Australian Feedlots’ provides data on the quantity of water required to produce red meat within the feedlot sub-system only. The Part A Report defined water usage as ‘*Managed water use denotes the consumption of self-extracted water (water from rivers, lakes and aquifers, mainly extracted by farmers for irrigation) as well as mains water, in units of litres (L). Collected rainfall, such as in livestock dams on grazing properties is not included in these figures’*. This is taken directly from Foran, Lenzen & Day (2005).

Peters (2006) re-examined the definition of water use to take into account all surface water intercepted and released or stored. Peters (2006) argued that some feedlots have made large investments in collecting all runoff from a large portion of their surface area in order to prevent any possibility of nutrient loading of creeks. This is a regulatory requirement. Where this water is reused for crop irrigation, this water use could be counted as part of the production system for crops within the property (and LCA system) boundary at the feedlot. In this situation it could be appropriate to count evaporative losses from such storages as water used in the delivery of irrigation.

It may be argued that it is not appropriate in the feedlot sub-system to include water collected in runoff in the definition of water use. This practical subtlety in the definition of water use will be re-examined in COMP.094 to ensure consistency in the research findings for the grazing system.

During the conduct of the LCI survey, it was found that total annual clean water records by lot feeders are usually good but little data exists on actual usage levels in individual components, viz. drinking water, feed processing and cattle washing. Water usage for individual components was determined from survey data and compared with estimated usage levels from best available prediction models.

Total annual water use was found to range from 34 L/kg HSCW gain to 381 L/kg HSCW gain with a median value of 73 L/kg HSCW gain over the nine feedlots studied.

Total annual water use depends upon the quantity of water used for dilution of effluent for irrigation. Feedlots with plenty of clean water available for irrigation used substantially more water per kg/ HSCW gain. The use of clean water for dilution of effluent pre-irrigation is very site specific.

Variation in water use between feedlots may be explained by variations in management including the frequency of trough cleaning, cattle washing, dust control and feed processing.

The data presented in the Part A Report will be used as inputs into the life cycle impact assessment (LCIA) phase in the analysis of the beef supply chain conducted in COMP.094.

5.5 Salinity

Salinity is a major problem in many agricultural areas in Australia. Salt, previously stored in the landscape is now being mobilised on a massive scale by rising groundwater tables due to land use changes across Australia. Salinity can usually be classified as either dryland salinity or irrigation-induced salinity.

In dryland salinity, clearing of trees or other landscape changes alters the extraction of rainwater from the soil profile causing accumulation and concentration of water in new areas. These are typically at the toe slope of hillsides. Salt in the soil profile is mobilised and concentrates in these toe slope areas resulting in salt scalds.

In irrigation-induced salinity, over application of irrigation water causes the groundwater table to rise, bringing salt with it into the upper soil layers.

Both of these types of salinity could be caused by feedlot developments. A feedlot could be constructed on the top of a hill from which all the vegetation needs to be cleared. This could result in dryland salinity outbreaks occurring below the feedlot site. Local over-application of effluent and clean irrigation water could cause local water tables to rise, bringing salt to the surface. In both cases, the onset of salinity would be very site specific and could not be generalised across the whole feedlot industry.

There is a third, less common, cause of salinity development. This involves the combination of irrigation with saline water with inadequate leaching to move the salt through the soil profile and below the root zone. This could occur at a feedlot if the effluent (runoff) was particularly saline and if inadequate monitoring of salt levels in the effluent and soil occurred. However, this is unlikely to be an issue because (a) the likelihood for salinity development should have been assessed during the planning phase of the feedlot development and (b) on-going monitoring should have detected the onset of salinity development and corrective actions should have been undertaken. In any case, this would also be very site specific and cannot be generalised across the whole feedlot sector.

A long-term objective for any reuse area should be to ensure that there are no consistent increases in soil salinity. Clearly there may be pronounced increases in soil salinity through the addition of effluent or solid by-products, particularly in the topsoil layer. However, these increases need to be offset by leaching losses to ensure no consistent and significant increases in soil salinity in the subsoil layers.

Addition of salt to land areas is an environmental issue for the following reasons.

- Soil salinity can reduce plant growth and yields through dehydration. This happens because the dissolved salts lower the potential for water to pass into the roots. Yields can decline by 20-30% before the signs of salinity are obvious (Salt Action 1999). Crops may also appear to be water-stressed even when supplied with adequate water. However, the effect is often more obvious in dry years (SalCon 1997).
- If crop yields are reduced significantly, bare soil patches may form. This significantly increases the risk of soil erosion.

- Different plants have differing abilities to take up saline water. Hence, the soil salinity influences the crops that can be grown and the composition of pastures. Excess levels of specific salts may also be a problem. For instance, sodium or chloride accumulating in plant leaves may produce leaf burning, necrotic patches and defoliation. An associated effect is a reduction in the availability of calcium and magnesium, which may produce deficiency symptoms. An excess of boron is expressed through yellowing of the margins, crumpling, blackening and leaf distortion (SalCon 1997).
- A high salt or sodium concentration can degrade soil structure, cause scalding and significantly increase erosion. The soil may appear fluffy and light under highly saline conditions (SalCon 1997).
- Salts leaching through the soil may reduce the quality of underlying groundwater.
- Saline runoff and soil erosion may reduce the quality of receiving surface waters.
- Highly saline soil solutions may mobilise heavy metals and other potentially toxic substances in the soil (Charman and Wooldridge 2000).

Salts added to the soil accumulate when there is preferential loss of water by evaporation or evapotranspiration, rather than by drainage. Consequently, salt accumulates in all but the most permeable soils. In the presence of shallow groundwater systems, salts tend to accumulate in the upper soil layers. Where water tables are at least 2 m below the soil surface, salt tends to accumulate at the base of the active root zone or at the depth of effective soil wetting. The extent of salt accumulation in the soil depends on the permeability of the soil (which influences leaching), the presence and type of vegetation (evapotranspiration) and the amount and seasonal distribution of rainfall. In high rainfall areas, soils have low salt accumulation because leaching is sufficient to remove surplus salts (Shaw 1999).

Many feedlots have operated for many years without any sign of salinity development in effluent or manure reuse areas.

Salinity will be addressed further in the COMP.094 project.

5.6 Soil Erosion

Information to assist feedlot operators to reduce nutrient and sediment delivery to streams by minimising and possibly reversing land degradation has focused on soil and wind erosion control within the feedlot area and sound management of effluent and manure reuse areas. Soil conservation measures are important to minimise erosion of nutrient-rich soil and other particles from reuse areas. Soil conservation measures may include:

- establishing and maintaining vegetated buffer zones along water courses.
- contour banks.
- strip cropping.
- minimum tillage.
- sound crop management.

- good soil management. For instance, sodicity prevention is important in effluent reuse schemes because of the relatively high sodium content of the effluent and the adverse effects of sodicity on soil structure and subsequent erosion rates.

Despite the various soil conservation measures that are undertaken, some soil erosion may still occur. The actual amount of soil erosion is very site specific and dependent on seasonal conditions. Any estimate of soil erosion from a feedlot's effluent and/or manure reuse areas would need to be undertaken using specific soil and cropping data for the site.

Further consideration and modelling of soil erosion will be undertaken in COMP.094.

5.7 Nutrient Management

Extensive research has been undertaken in the areas of animal growth and composition and the factors that influence feed intake and digestibility, feed composition and waste management. Despite this, there is a wide variation in reported values for feedlot cattle nutrient excretion. Over the past ten years, there has been a significant development of the feedlot industry in terms of feeding for specific markets and in manure management. However, research into N losses through volatilisation of ammonia (NH_3) and nitrous oxide (N_2O) from feedlots systems has not kept pace with these changes.

Data on the quantity of the major nutrients supplied to the feedlot and the fate and quantities of nutrients leaving the feedlot is provided in Part C Report – 'Nutrient Cycling at Australian Feedlots'.

Site-specific information on cattle numbers, diet ingredients, market type, days on feed, quantity of manure produced and effluent concentrations was collected where possible from nine feedlots. The life cycle inventory for N, P and K within the feedlot sub-system was determined.

N enters the feedlot in incoming cattle (0.05-0.12 kg/kg HSCW gain) and feed (0.15-0.33 kg/kg HSCW gain). The contribution of N from diet ingredients was found to range from 60-87% of the total N input. The level of N contained in individual diets varies between feedlots and within feedlots.

N is removed from the system in outgoing cattle (0.08-0.13 kg/kg HSCW gain) and manure (0.13-0.30 kg/kg HSCW gain). Hence, most N exits the feedlot in manure (50–80 %). Approximately 80% of the manure N is lost to the atmosphere from volatilisation, with the remainder exported in effluent and scraped manure.

The total P input level is around one-fifth of the total N input. It enters the system in incoming cattle (0.012-0.029 kg/kg HSCW gain) and feed (0.028-0.054 kg/kg HSCW gain). The contribution of P from feed is 47-80% of the total P input. P exits the system in outgoing cattle (0.023-0.038 kg/kg HSCW gain) and in manure (0.017-0.039 kg/kg HSCW gain). Variations in diet composition influence the level of P in manure, with long-fed cattle having higher P concentrations in their diet and hence in their manure. P is present in scraped manure at 94-99% of the total P excreted in manure. The balance is contained in the effluent.

The total K into the system was 0.05-0.13 kg/kg HSCW gain. This is similar to the P inputs and around one-fifth of the total N inputs. Over 90% of the K into the system comes from feed. K out of the system is partitioned between outgoing cattle (0.01 kg/kg HSCW gain) and manure (0.06-0.09 kg/kg HSCW gain). The K output rates vary significantly between feedlots. This is mainly due to dietary variation, with predominantly long-fed cattle offered diets that have a high roughage content and hence a high K content. The percentage of K retained in scraped manure ranges from 65-99%. The balance is exported in effluent.

The outcomes of this study will allow the feedlot industry to develop a better understanding of the relativity and pathways for nutrient cycling and provide factual information on the life cycle inventory for major nutrients.

Knowledge of the total nutrient input and output levels will allow the industry to benchmark itself against other intensive or extensive livestock industries and or industrial processes. More research into NH_3 and N_2O losses from Australian feedlot pads, manure stockpiles and compost heaps, holding ponds, manure spreading and effluent irrigation is warranted. Further research into methods for minimising NH_3 and N_2O losses from feedlot systems is also recommended.

5.8 Soil Acidification

Soil acidification is the accumulation of acid in the soil and is one of Australia's largest land degradation problems. It is estimated to affect more than 50 million ha of agricultural land (National Land and Water Resources Audit 2001). Although soil acidification is a natural process it may be accelerated by agricultural practices. The rate of soil acidification depends on the rate of acid addition to the soil and is broadly related to:

- Soil type: Acidity developed more rapidly on lighter textured soils than on heavier clay soils.
- Rainfall: High rainfall areas experience increased leaching of nutrients leading to increased acidification.
- Land use: agricultural production increases the rate of acidification through the removal of agricultural products, leaching of nitrogen as nitrate below the plant root zone, commonly from legume based pastures, use of nitrogen fertilisers and build up of organic matter.

High acidity levels generally result from repeated applications of NH_3-based fertilisers without liming, and the growing of pastures based on legumes such as subterranean clover. Such pastures tend to die off in summer and, with nothing to use the N, it leaches through the soil, increasing soil acidity instead of being used for plant growth. However, soil acidity is not confined to areas under annual pastures or crops. As acidity increases elements like P and molybdenum that are important to plant nutrition become less available. At the same time, aluminium and manganese, which are toxic at high levels, become more readily available and soluble in soil water. Because it often takes twenty to fifty years for plant yields to decline in response to acidification, induced soil acidity has only emerged since the mid-1970s, but it is now seen as one of the most serious of all problems and one of the most neglected (AACM International 1995). Nutrient availability problems arise when the soil pH drops below about 5.5. Degradation caused by soil acidification occurs on-site through decline in production. It is also likely to cause off-site impacts, such as decline in stream pH and potential for increased erosion on steeper slopes due to decreased plant cover.

The technical solutions available to reduce the rate of acidification and to increase the soil pH are to apply lime and/or to change the farming system. However, while liming can reverse top soil acidity, subsoil acidification is a far more intractable problem.

In this context, the consideration of soil acidity should not be confused with acid sulfate soil conditions which have very low ph and are found in environments where pyrite occurs in the soil. Acid sulfate soils occur in coastal marine environments, saline discharge areas and mine tailings. There is no known occurrence of acid sulfate soils at feedlot sites involved in this study.

Most of the NH_3 from animal manure volatilizes into the atmosphere and plays an important role in soil acidification and eutrophication (Bouwman and Van Der Hoek, 1997). (The amount of ammonia volatilized from feedlots is discussed in the Part C Report – 'Nutrient Cycling at Australian Feedlots').

According to Schoenau (2005), the effect of manure on soil pH is variable. Repeated applications of fertilizer N may lead to soil acidification (Ukrainetz et al. 1996) due to acidity produced in the nitrification process (microbial oxidation of ammonium to nitrate). While organic matter added as manure can act to help buffer the soil against a decrease in pH, manure that is low in organic matter and high in NH_4 nitrogen may result in a decrease in pH due to acidity produced when the NH_4 is oxidized to nitrate in the soil. Chang et al. (1990) observed a decrease in soil pH with time and suggested that some soils might eventually become acidic with continued application of manure. Whalen et al. (2000) in an eight week study conducted in the laboratory, reported an immediate increase in the pH of two acid soils from northern Alberta following fresh cattle manure application and concluded that the effects of manure on soil pH would depend on the manure source and soil characteristics. Manures with a high organic matter and carbonate content would be most effective in raising the pH of an acid soil and in buffering against changes in pH once in the soil.

There appears to be no published information regarding the acidification of soil from application of feedlot effluent or manure in Australia. However, given the experiences in broad-acre agriculture, it is probable that soil acidification could develop at some feedlot sites – probably due to the leaching of nitrate below the root zone. This should be evident in annual soil monitoring results as required by regulatory agencies and should be addressed on an individual site basis.

Soil acidification will be addressed in more detail in COMP.094.

5.9 Weeds

Weeds are invasive exotic species and other pest species that impact on the biodiversity, ecology, sustainable production and community of an area. Because of their greater competitiveness, weed species readily invade bare areas of ground which have been denuded of vegetation. Drought, fire and even floods can create these conditions as they devastate existing ground cover, thereby removing all competition for light, nutrients, moisture and space. This devastation allows quick weed establishment when more favourable conditions arrive. Weeds already on the property may quickly spread to new areas, and weed densities increase.

Classes of land most at risk of weed invasion are cropping and pasture land and denuded land around feedlots. Cropping land is most at risk through weed imports in contaminated seed at sowing time, weed seed being spread from machinery—especially harvesters and the distribution of feedlot manure for use as a fertiliser which is thought to be responsible for viable weed seed distribution.

Adverse publicity resulting from actual and perceived risk of introducing viable weed seeds threatens to reduce the saleability of feedlot manure. This may have serious implications for feedlots depending upon off-site use of manure because of limited on-farm manure utilisation areas.

Feed processing, ruminant digestion, wetting and drying in the feed yard and heat generated during storage is thought to sterilise most plant seeds. However, there are observed situations where weed problems have increased following manure spreading (Evan Powell Rural Consultants 2001).

Herbicide chemical use in the feedlot and on surrounding farming area was required to be input into the survey. Herbicide use around the feedlot was found to be very limited and a very small proportion of total chemical use, typically less than 5%. Herbicide use is just one way to control weeds, hence these data do not identify the extent of weed problems at feedlots. It is also not surprising that it is a small percentage of total chemical use at a feedlot. However, it is important to have a strategy in place for combating potential weed problems before, not after, they occur. Weed hygiene around the pen area, manure storage areas, reuse areas and care when loading out will assist in reducing infestation.

Grazing land is at risk of weed importation through contamination of fodder. Weed seed may be inadvertently spread around a property at the time of feeding, or in the animals' dung, days after the contaminated fodder has been eaten. The presence of livestock on a property will usually allow some weeds to establish to the detriment of desirable species as these weeds are often less palatable and are therefore not readily grazed. These types of issues will be addressed in the COMP.094 project.

5.10 Feral Animals

Feral animals are perceived to have a potential impact on the feedlot business and the surrounding environment. These impacts could include:

- competition with livestock for resources (food, water).
- predation on carcasses.
- damage to grain and horticultural crops.
- soil disturbance and general land degradation.
- damage to fences and water sources, and
- disease threat (biosecurity issues).

As part of the LCI survey, respondents were asked if feral animals were considered a problem for their business. If so, the type of feral animal/s considered the most significant was required to be input into the survey. Approximately 50% of the survey respondents considered they had a problem with feral animals at their feedlot and surrounding farm. Foxes were the predominant feral animal and posed a problem at two feedlots, whilst deer, birds and mice presented a problem at three separate feedlots respectively. Birds were especially a problem, damaging irrigated crops and cleaning up spills around feedmills and feed bunks. Feral animals are controlled though programs of controlled culling (deer) or baiting.

Feral animals are not a major NRM issue at feedlots and will be discussed in greater detail in the COMP.094 project.

5.11 Biodiversity

Biodiversity decline is most closely linked to habitat destruction. As the immediate footprint of feedlots is quite small and as most feedlots are built on already cleared sites, the direct biodiversity decline impact of feedlots is quite small. In fact, many feedlots plant trees to act as visual screens and buffers and these probably improve the natural environment surrounding a feedlot.

The greater biodiversity decline of feedlots would be indirect through:

- the production of feed grain and other commodities to be used by the feedlot.
- the breeding of cattle for use in the feedlot.
- off-site impacts of nutrient releases to the air and water.

These indirect impacts will be discussed in the COMP.094 project.

5.12 Vegetation Management

Vegetation management is similar to biodiversity decline. Because feedlots have small footprints and because most feedlots are built on already cleared sites, remnant vegetation should not be significantly adversely affected by feedlots. In many areas, clearing of remnant vegetation to allow for construction of a feedlot would be banned. Many feedlots plant trees to act as visual screens and buffers and these would probably result in a net increase in vegetation around a feedlot.

The greater vegetation management impact of feedlots would be indirect through:

- the production of feed grain and other commodities to be used by the feedlot.
- the breeding of cattle for use in the feedlot.
- off-site impacts of nutrient releases to the air and water.

These indirect impacts will be discussed in the COMP.094 project.

5.13 Energy Efficiency and Greenhouse Gas (GHG) Emissions

Energy is fundamental to a feedlot production system. Little work has been undertaken on energy use at feedlots and there have been no published studies to date for Australian feedlots.

This project was able to produce quantitative data on energy use and GHG emissions from feedlots for use in the COMP.094 LCA work.

This project reviewed previous research into energy consumption and GHG emissions from feedlots. Factual data on energy use in Australian cattle feedlots under a range of climatic, size and management conditions was collected from nine feedlots over the 2002 and 2004 years. GHG emissions were then estimated using Australian Greenhouse Office (AGO) standard methodology. FLOT.328 Final Report Part B - ‘Energy Usage and GHG Emissions at Australian Feedlots’ - provides a comprehensive account of the energy usage and GHG emissions at Australian feedlots.

Data to estimate energy use was obtained via the LCI survey of feedlot inputs and outputs including cattle numbers, intake and sale weights, dressing percentages, mean distance travelled to and from the feedlot and energy consumption. Annual energy usage was estimated on the basis of one kilogram of HSCW gain.

In 2002, total energy consumption was found to range from 1.14 to 17.8 MJ/kg HSCW gain. In 2004, a smaller range was found with a maximum total energy of 1.4 to 12.8 MJ/kg HSCW gain.

Distance travelled by delivery trucks has a large impact on energy consumption through incoming and outgoing cattle and commodity (feed) delivery. Sourcing cattle and commodities close to feedlots and locating feedlots close to abattoirs minimises energy consumed in these processes. Cattle sourced close to feedlots have lower (0.5-1.25 MJ/kg HSCW gain) energy consumption when compared with feedlots that source cattle from greater distances (2.5-3.0 MJ/kg HSCW gain). Commodities sourced close to feedlots have lower (0.5 MJ/kg HSCW gain) energy consumption than feedlots that source commodities from greater distances (1.5-3.5 MJ/kg HSCW gain).

Feed processing is the single largest consumer of energy in the feedlot sub-system and can account for up to 70% of the total energy consumption. The amount of energy needed for feed processing depends upon the processing system. Energy consumption ranges from 0.25 MJ/kg HSCW (tempering) to 4.4 MJ/kg HSCW gain (steam flaking). Feedlots using steam flaking use more than nine times the energy for feed processing compared with those that reconstitute or temper their grain.

Feed delivery and pen cleaning/maintenance are the second largest energy consumers in the feedlot sub-system, accounting for 15-40% of total energy usage. Pen cleaning frequency, pen layout, location of pens in relation to the feedmill and feed truck age and type contribute to feed delivery/pen cleaning & maintenance energy consumption.

Energy used in water supply, administration, irrigation and other farming activities comprise the balance of the energy used in feedlots, at about 10% of the total energy consumption.

GHG emissions were estimated using standard AGO methodology for feedlots. This methodology does not appear to accurately reflect the manure and effluent management systems used at Australian feedlots and may underestimate GHG emissions, particularly from manure management. The conclusions drawn below are based on standard AGO methodology. It is strongly recommended that research on GHG emissions from cattle feedlots be undertaken to refine the methodology.

Enteric methane represents the greatest single source of GHG emissions from the feedlot sub-system accounting for up to 75% of total emissions. Enteric methane emissions depend on the class of cattle in the feedlot with longer fed cattle (> 150 days) having a higher enteric methane production than shorter fed cattle (< 150 days).

Emissions of manure nitrous oxide are the second largest source of GHG emissions, accounting for 20% of total emissions. Manure methane accounts for 1% of total GHG emissions. The default methane conversion factor (MCF) value of 5% and 1.5% from the AGO standard methodology was used in the calculation of manure methane for ‘warm’ regions (Queensland) and ‘temperate’ regions (NSW, Victoria) respectively. Thus, no consideration is given for anaerobic (wet pen) conditions in feedlot pens following rainfall. If MCF is typically closer to the 66% for a wet anaerobic pen surface (as estimated by Steed and Hashimoto (1995)), then the AGO method under-predicts emissions from manure methane.

Combined emissions from the energy consumed during livestock and commodity transport, feed processing, feed delivery and water supply account for 4% of the GHG emissions. Of these sectors feed processing can have the highest emissions, depending on the type of processing system.

The data presented in the Part B report will be used as inputs into the life cycle impact assessment (LCIA) phase in the analysis of the beef supply chain conducted in COMP.094.

5.14 Solid Waste

In conventional LCA, solid waste refers to the wastes that must be disposed of in landfills. For feedlots, this would include regulated and non-regulated wastes. Regulated wastes from feedlots would include old tyres, spent oil and chemical containers. Unregulated waste would include office materials (waste paper, etc) and general packaging.

Most feedlots responding to the survey did not have good records of solid waste disposal. However, the data supplied indicated that the amounts were very small when expressed on a per kg HSCW basis. Many feedlots recycle solid wastes (old tyres, spent oil, waste paper).

The largest amount of “solid waste” produced at feedlots is manure and other organic matter. Extensive research has been undertaken in the areas of animal growth and composition and the factors that influence feed intake and digestibility, feed composition and waste production. Over the past ten years, there has been a significant development of the feedlot industry in terms of feeding for specific markets to minimise feed intake (and thus manure production) and in manure management.

Factual information on the quantity of solid organic waste produced is provided in Part C report – ‘Nutrient Cycling at Australian Feedlots’.

Factual site-specific information on cattle numbers, diet ingredients, market type, days on feed, quantity of manure produced and manure management system employed was collected where possible from nine feedlots. Most feedlots surveyed (66%) mounded manure in pens after cleaning. The mass of manure in mounds ranged from 200-250 t before transfer to the designated stockpile area. Two feedlots were unable to provide data on manure management. Pen cleaning was undertaken on a fixed schedule (66% of feedlots) or at correct moisture content. All feedlots stockpiled manure within a designated stockpile area. Two feedlots occasionally turned manure in the stockpile whilst a small percentage (30%) screened manure before reuse. All feedlots composted livestock carcasses within the manure stockpile area.

6 Success in Achieving Objectives

The largest component of the FLOT.328 project was to obtain parameters for the life cycle inventory analysis of the feedlot sub sector so that the impact assessment on the beef supply chain can be undertaken in COMP.094.

Gathering parameters for the life cycle inventory was undertaken by a detailed survey of feedlot inputs and outputs. A detailed account of the survey form can be found in FLOT.328 Milestone 2 report (Watts 2005). This survey was undertaken on-line to minimise the travel requirements of researchers and for every feedlot surveyed allow their feedlot managers to enter data at their convenience.

Data was collected for two calendar years being 2002 and 2004. The intent was to have data from two years of differing climatic conditions viz drought v good year. Differing climatic conditions impact on feedlot occupancy and resource use (e.g. water and feed intake)

A wide range of data was collected with the objective of providing enough information to undertake the impact assessment required. The data collected included the following:

1. Data on cattle numbers, intake and sale weights, dressing percentages and other parameters that allow red meat production to be estimated for two years (2002 & 2004). This data could be analysed to determine the tonnage of HSCW gain in the feedlot over a 12-month period. Cattle numbers were broken down into each main market type so that later analysis would be able to determine if different market types had different environmental impacts.
2. Feed usage data for the same two years broken down into each commodity.
3. Clean water usage (ML/yr) broken up by drinking water, cattle washing, feed processing, farm/office, effluent shandy irrigation and clean water irrigation for two years (2002 & 2004).
4. Energy usage broken down into energy type (diesel, electricity, gas, etc.) and area of usage.
5. Estimates of haulage distances for cattle into and out of the feedlot and for feed commodities into the feedlot.
6. Staff numbers
7. Manure and effluent production
8. Usage of chemicals including veterinary, herbicide and pesticide chemicals.
9. Environmental performance assessed by the range of environmental management systems implemented at each feedlot.

The majority of information collected in the survey was used directly as a quantitative parameter for the life cycle impact analysis and is presented in FLOT.328 reports A to F inclusive. However, some information gathered in the survey was not presented in the FLOT.328 reports (viz chemical usage, commodity usage) but nevertheless will form an important component of the life cycle phase in the analysis of the beef supply chain conducted in COMP.094.

7 Impact on Meat and Livestock Industry – now & in five years time

All components of the red meat supply chain face increasing scrutiny as to their management of the natural resources from which the industry derives its productivity. As a result measurement, reporting and public perceptions are priority issues for the feedlot sector together with the following environmental issues:

A wide range of data was collected in this project with the objective of providing enough information to undertake a detailed impact assessment. Factual data on water quality; water use efficiency; nutrient management, feral animals; energy use and greenhouse gas estimation was collected. These issues vary between production systems. This information will allow the feedlot industry to be well placed to manage and counteract public perceptions on environmental resource issues. However, this study also identified a number of gaps in the knowledge on environmental issues.

8 Conclusions and Recommendations

8.1 Conclusions

The basic function of a feedlot is to provide suitable accommodation, feed, water and care to cattle so that they can grow optimally. The components of a feedlot include pens, feed alleys, drains, cattle handling facilities, waste management systems and administration facilities. Like all farming activities, feedlots have the potential to cause environmental harm and damage to natural resources. However, the risk of this occurring can be minimised through good siting and the use of good design and management processes throughout the feedlot system.

In the context of a Life Cycle Assessment, the feedlot-relevant natural resource management (NRM) issues identified as issues of concern to the red meat industry were assessed. The largest component of the project was the life cycle inventory (LCI) which enabled the impact assessment to be undertaken. A detailed survey of feedlot inputs and outputs was undertaken using an on-line survey to collect data for the LCI.

A wide range of data was collected with the objective of providing enough information to undertake the impact assessment required. The data collected included data on cattle numbers, intake and sale weights, dressing percentages and other parameters that allow red meat production to be estimated for two years (2002 & 2004). Cattle numbers were broken down into each main market type so that later analysis could be used to find if different market types had different environmental impacts.

Data was collected on feed usage data broken down into each major commodity, clean water usage (ML/yr) broken up by volume used for drinking, cattle washing, feed processing, farm/office, shandying effluent for irrigation and clean water irrigation, energy use, staff numbers, manure and effluent production, usage of chemicals including veterinary, herbicide and pesticide chemicals and environmental performance assessed by the range of environmental management systems implemented at each feedlot.

Data were collected from nine feedlots ranging in size from 1000 head to 25,000 head and geographically spread from Victoria to Queensland.

Feedlots have the potential to affect the quality of surface water bodies and groundwater. The key risks to water quality arise from the nutrients (N,P,K) and salts concentrated in feedlot by-products, although properties like biological oxygen demand (BOD), solids content and heavy metal concentrations could also potentially reduce water quality.

Water is both the most important nutrient for cattle and the most valuable natural resource (after land) in Australia. Hence, it is of critical importance to lot feeders. The Part A Report - ‘Water Usage at Australian Feedlots’ provides data on the quantity of water required to produce red meat within the feedlot sub-system only.

Salinity is a major problem in many agricultural areas in Australia. Salt, previously stored in the landscape is now being mobilised on a massive scale by rising groundwater tables due to land use changes across Australia. Salinity can usually be classified as either dryland salinity or irrigation-induced salinity.

Information to assist feedlot operators to reduce nutrient and sediment delivery to streams by minimising and possibly reversing land degradation has focused on soil and wind erosion control within the feedlot area and sound management of effluent and manure reuse areas. Soil conservation measures are important to minimise erosion of nutrient-rich soil and other particles from reuse areas. Soil conservation measures may include:

There appears to be no published information regarding the acidification of soil from application of feedlot effluent or manure in Australia. However, given the experiences in broad-acre agriculture, it is probable that soil acidification could develop at some feedlot sites – probably due to the leaching of nitrate below the root zone. This should be evident in annual soil monitoring results as required by regulatory agencies and should be addressed on an individual site basis. Soil acidification will be addressed in more detail in COMP.094.

Herbicide chemical use in the feedlot and on surrounding farming area was required to be input into the survey. Herbicide use around the feedlot was found to be very limited and a very small proportion of total chemical use, typically less than 5%. Herbicide use is just one way to control weeds, hence these data do not identify the extent of weed problems at feedlots. It is also not surprising that it is a small percentage of total chemical use at a feedlot.

As part of the LCI survey, respondents were asked if feral animals were considered a problem for their business. Feral animals are not a major NRM issue at feedlots and will be discussed in greater detail in the COMP.094 project.

Biodiversity decline is most closely linked to habitat destruction. As the immediate footprint of feedlots is quite small and as most feedlots are built on already cleared sites, the direct biodiversity decline impact of feedlots is quite small. The greater biodiversity decline of feedlots would be indirect such as the production of feed grain, breeding of cattle for use in the feedlot and off-site impacts of nutrient releases to the air and water. These indirect impacts will be discussed in the COMP.094 project.

Energy is fundamental to a feedlot production system. This project was able to produce quantitative data on energy use and GHG emissions from feedlots for use in the COMP.094 LCA work. FLOT.328 Final Report Part B - ‘Energy Usage and GHG Emissions at Australian Feedlots’ - provides a comprehensive account of the energy usage and GHG emissions at Australian feedlots.

In conventional LCA, solid waste refers to the wastes that must be disposed of in landfills. For feedlots this would include regulated and non-regulated wastes. Regulated wastes from feedlots would include old tyres, spent oil and chemical containers. Unregulated waste would include office materials (waste paper, etc) and general packaging.

Most feedlots responding to the survey did not have good records of solid waste disposal. However, the data supplied indicated that the amounts were very small when expressed on a per kg HSCW basis. Many feedlots recycle solid wastes (old tyres, spent oil, waste paper). Factual information on the quantity of solid organic waste produced is provided in FLOT.328 Final Report Part C – ‘Nutrient Cycling at Australian Feedlots’.

8.2 Recommendations

The largest component of this project was the life cycle inventory (LCI) which enabled the impact assessment to be undertaken. A detailed survey of feedlot inputs and outputs was undertaken using an on-line survey to collect data for the LCI.

A wide range of data was collected with the objective of providing enough information to undertake the impact assessment required. The data collected included data on cattle numbers, intake and sale weights, dressing percentages and other parameters that allow red meat production to be estimated for two years (2002 & 2004). Cattle numbers were broken down into each main market type so that later analysis could be used to find if different market types had different environmental impacts.

After data was entered into the survey by lot feeders, the data was entered into a large Feedlot System Analysis Model spreadsheet (FSA Model) where varies parameters were calculated and data quality checks were undertaken. Where anomalous data was detected, the participating feedlot was contacted and the data was examined in more detail.

However, in some cases there still remained a mismatch between the mean number of cattle on hand estimated by the FSA model and that given in the survey. In most cases this was due to the yearly cattle number data and summary mean cattle on hand entered into the survey which does not capture monthly fluctuations. Hence, it is recommended that the survey continue to be undertaken on a monthly basis so as to collect factual data on mean number of cattle on hand.

Whilst, the type and detail of the information collected in this project allowed the total water consumption from feedlot operations to be estimated, few feedlots were able to accurately partition the water use into individual sectors. This information would be invaluable in optimising the design and management of cattle feedlots and in better explaining the natural resource use.

Hence, it is recommended that industry undertake further research into water consumption in feed processing, cattle washing and drinking water. The fact that large amounts of water are consumed in drinking water livestock is of course, well known to the industry. However, what factors influence daily water consumption and diurnal variation is not well known but may become important to the industry in a way it has not been before.

More research into NH_3 and Nitrous Oxide (N_20) losses from Australian feedlot pads, manure stockpiles and compost heaps, holding ponds, manure spreading and effluent irrigation is recommended. This would enhance knowledge about the magnitude of these losses to the atmosphere and provide better information for managing reuse of manure and effluent. In addition, knowledge of N_20 losses would allow improvement in the estimation of GHG emissions.

Further research into methods for minimising NH_3 and N_20 losses from feedlot systems is also recommended. This would enable N to be retained in manure and effluent where it is a valuable plant nutrient. It would also enable the minimisation of NH_3 emissions to the atmosphere.

Whilst the type and detail of the information collected in this study allowed evaluation of total energy consumption and relativity between feedlot operations it did not consider the partitioning of energy consumption between feed delivery and manure management. The energy consumption of these two operations is important for assessment of alternative management practices. Hence further research in this area is recommended. This may include the type of manure management system used (mounding v more frequent removal) and the efficiency of feed delivery i.e. pen layout relative to feed processing systems, feed delivery management (1 larger capacity truck v 2 smaller capacity trucks etc). Gaining a better understanding of the efficiency of feed delivery may also be an important consideration in optimising feedlot layouts.

The emissions from manure nitrous oxide and methane are the second and third largest sources of GHG emissions respectively, accounting for around 21% of total GHG emissions. The AGO method gives no consideration is given for emissions from manure management systems other than dry pen conditions. Hence, it is strongly recommended that research on GHG emissions from manure under different management conditions be researched.

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