final report

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Prepared by: Dr Benjamin Jones
Dr Kimberley Wockner
Dr Kevin Sullivan
Lucy Richardson
Tim Sullivan
Dr Peter Watts

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

Feedlot dust suppression review

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Abstract

Dust generation can be an issue for many Australian feedlots and can adversely impact livestock, employees and the community. Within a feedlot, the sources of dust generation can be categorised as manure-related, traffic-related and feed-related. Consultation with Australian lot feeders and a detailed literature review was conducted to review currently available technologies and strategies to suppress dust in the feedlot environment and identify new research and development opportunities to suppress dust. Within this report, the findings for each of the dust sources are addressed as follows:

1. Description of dust generation;
2. Data on dust components;
3. Impacts of dust on livestock, employees, contractors, and the community; and
4. Dust hierachial hazard control.

By following the hierarchy of hazard control, dust from Australian feedlots should not be a health issue to humans or animals, and should only be assesed as a nuisance.

Executive summary

Dust is generated in feedlots from a variety of sources including animal activity in pens, pen maintenance, manure management, traffic, and feed storage and processing. Dust generation can be an issue for many Australian feedlots and has the potential to impact on the health and safety of livestock, employees and the surrounding community.

In this report, the sources of dust generation are categorised as manure-related, traffic-related and feed-related. Following consultation with Australian lot feeders, a detailed literature review investigating the main dust sources has been completed, as follows:

1. Description of dust generation;
2. Data on dust components;
3. Impacts of dust on livestock, employees, contractors, and the community; and
4. Dust hazard control using a hierarchy of hazard control.

Hierarchy of hazard control is a system used in industry to minimize or eliminate exposure to hazards. Current dust reduction strategies from within the feedlot industry have been reviewed using a hazard control hierarchy, as was any new or alternative technologies from other industries, such as construction, mining and quarrying. The hazard controls in the hierarchy, in order of decreasing effectiveness, are:

- Elimination;
- Substitution;
- Engineering;
- Administration; and
- Personal protective equipment.

Regardless of the source of dust, dusty conditions are the result of a fine dry material becoming airborne. Manure-related dust is derived from manure from pen surfaces, which can be problematic when pad moisture is low (i.e. < 20%). Low pad moisture may be the result of low stocking densities, or low rainfall, particularly during the summer months. These dry conditions increase dust generation, which is aided through wind and cattle movement, cattle handling and manure management.

Manure-related dust contains a complex mix of organic and inorganic particles. Bedding, hair, skin scurf, insect parts, mites, fungi, bacteria and toxins are all components of manure-related dust which may have potential to cause health problems in cattle and humans. However, no conclusive evidence could be found to support or contradict this theory. Q-fever is a significant infectious disease which spreads from animals to humans through aerosols, contaminated dust, animal products and manures. All workers or visitors exposed to cattle are required to be vaccinated against Q-fever (see Section 4.3.3.2), or wear appropriate personal protective equipment (PPE) which minimises the inhalation of contaminants through the respiratory route (see Section 4.4.5).

Manure-related dust can be managed through elimination, i.e. manure removal or pen moisture management (through stocking density manipulation, or sprinkling systems), or substitution of open feedlot pens with fully-covered sheds. However, all options have associated constraints, including increased dust creation (i.e. during manure removal), current regulatory environment, water availability or economic feasibility. Stocking density manipulation (see Section 4.4.1.3) appears to be a particularly successful and cost effective dust control strategy, although this is heavily constrained by current regulation and heat load factors may also be a concern.

Engineered or physical controls of manure-related dust include windbreaks, pen design, use of bedding material, water curtains or use of a buffer (separation distance) between the dust source and the community. Administrative controls would include time-of-day and week controls, wind direction control, climate prediction control and feed management. Finally, the use of personal protective equipment may assist with minimising dust inhalation or eye irritation and reduce any impact on human health.

Traffic-related dust is generated from unpaved road surfaces from wind, feed trucks, and other vehicle traffic. As discussed with manure-related dust, emissions are greatest when surface moisture is low and when fines content is high.

Since traffic-related dust is primarily derived from unpaved road surfaces, dust is likely to have a significant inorganic component, and reduced organic matter concentrations. Impact to humans and livestock is due to inhalation of fine PM, particularly for abrasive non-biodegradable particulates such as silica which can become deposited deep in the lungs, and can lead to health complications such as silicosis.

Road sealing eliminates traffic-related dust by removing the source of fine particulates required for dust generation. The sealing of roads is costly, although this strategy has successfully been employed by some Australian lot-feeding operations. Other traffic-related dust controls include effective road design, and dust suppression treatments (water and chemical). These treatments may be subject to water availability, or regulation (i.e. chemical treatments).

Finally, feed-related dust may be created through tub grinding feed, depositing the feed into the hopper, and depositing the feed into the feedbunk. However, there are numerous successful strategies used to control feed-related dust. Elimination of feed-related dust can be achieved by adding moisture to the grain, i.e. through steam flaking. Water requirements for steam flaking are relatively minor, meaning that water availability constraints are not applicable.

There is a lack of consensus regarding the most significant source of feedlot dust emissions, with general opinion being divided between manure-related or traffic-related dust. Feed-related dust is generally considered a minor source of overall dust emissions by all feedlot managers surveyed.

In short, the take-home message of this report is that by following the hierarchy of hazard control, dust from Australian feedlots should not be a health issue to humans or animals. If the hierarchy of hazard control is followed, dust should only be a nuisance.

Further research and development is recommended to investigate:

- Variable stocking densities
- Cattle urinary output research
- Water requirements for effective dust suppression
- Dust suppression cost benefit analysis

Fact sheets for feedlot staff have been developed on:

1. Sources and characteristics of dust;
2. Hierarchy of hazard control;
3. Pen-related dust; and
4. Traffic-related dust

These can be found in the appendices to this report.

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Abbreviations

ADG	Average Daily Gain (of livestock liveweight)
ALFA	Australian Lot Feeders' Association
BRD	Bovine Respiratory Disease
CFU	Colony-Forming Unit
DOF	(Days on Feed) means the difference between the exit date and the entry date of feedlot cattle
EC	Electrical Conductivity
EDP	Evening Dust Peak
ET	Endotoxin
G:F Ratio	(Gain : Feed Ratio) is synonymous with the feed conversion ratio
IBR	Infectious Bovine Rhinotracheitis
MLA	Meat & Livestock Australia
NLIS	National Livestock Identification Scheme
NPI	National Pollutant Inventory
ODTS	Organic Dust Toxic Syndrome
PM	Particulate Matter
PPE	Personal Protective Equipment
PSD	Particle Size Distribution
Pulls	Cattle which have been pulled from their home pen for treatment
PVC	Packed cell volume
SAR	Sodium Adsorption Ratio
TEOM	Tapered Element Oscillating Microbalance
TSP	Total Suspended Particulates
TWA	Time Weighted Average
µg/h	µg exposure per hour
WBC	White Blood Cell

1 Background

Dust generation can be an issue for many Australian feedlots. There are three main areas where dust may cause impacts. They are:

- Livestock: (animal welfare and production),
- Employees and contractors: (occupational health and safety), and
- Community (amenity and health).

Dust is generated in feedlots from a variety of sources including animal activity in pens, pen maintenance, manure management, traffic on on-site roads and access roads, and feed storage and processing. In this report, the sources of dust generation have been categorised as:

Source	Cause
• Manure-related	animal activity, pen cleaning and manure management,
• Traffic-related	traffic on on-site and access roads, and
• Feed-related	feed storage and processing.

Each source of dust has been investigated and the specific impacts have been discussed. Current hazard reduction strategies from within the feedlot industry have been reviewed using a hazard control hierarchy, as was any new or alternative technologies from other industries, such as construction, mining and quarrying.

Recommendations on the best abatement strategies for dust suppression for all three sources of dust have been included. Dust exposure limits for animals, employees and contractors, and the community are proposed. Fact sheets aimed at feedlot employees and contractors have been produced to raise awareness of current best practice for the identification and management of excessive dust.

Improved dust management aligns with MLA's meat industry strategic plan priorities (2016-2020) of animal welfare, production efficiency and building industry capability (MLA 2016b).

2 Project objectives

As outlined in the research agreement, the project objectives are:

1. Review available technologies and strategies to suppress dust in the feedlot environment which addresses (but is not limited to):
    a. strategies to detect when dust-load is problematic
    b. available technologies and strategies to suppress pen and road dust
    c. animal health impacts
    d. occupational health and safety impacts
    e. air quality impacts on surrounding neighbours
    f. recommendations to limit exposure of dust to animals, workers and neighbours.

2. Identify research and development opportunities to suppress dust in the feedlot environment.

3. Develop, in addition to the final report, a fact sheet that can be used by feedlot staff.

3 Methodology

3.1 Overview

This study is a desktop assessment which draws on publicly available information, including, but not limited to, peer-reviewed journals, industry reports and on-line searches. Australian lot feeders and overseas researchers from the USA have been consulted in the preparation of this review. Established relationships with researchers from the USA, who are currently conducting dust mitigation work, have assisted in the information gathering process.

The results and discussion are reported for each of the three dust sources (manure, traffic and feed) using the following structure to the reporting.

1. Description of dust generation
2. Data on dust components
3. Impacts of this dust on livestock, employees and contractors, and the community
4. Dust hazard control using a hierarchy of hazard control.

3.2 Hierarchy of dust hazard control

Hierarchy of hazard control is a system used in industry to minimize or eliminate exposure to hazards. It is a widely accepted system promoted by numerous safety organizations. This concept is taught to managers in industry, to be promoted as standard practice in the workplace. The hazard controls in the hierarchy (Fig. 1) are, in order of decreasing effectiveness:

- Elimination
- Substitution
- Engineering
- Administration
- Personal protective equipment

Fig. 1 – Hierarchy of dust hazard control

At a feedlot, dust hazard needs two elements for it to occur. Either of these two elements can be addressed to reduce dust hazard. They are:

1. A source of fine, dry matter with small particles sizes, and
2. A means for the dust to become airborne, being livestock movement, traffic or wind.

3.2.1 Elimination

Elimination of the hazard (i.e. physically removing it) is the most effective hazard control. For example, bitumen sealing of all feedlot roads could eliminate dust generated by traffic.

3.2.2 Substitution

Substitution, the second most effective hazard control, involves replacing something that produces a hazard (similar to elimination) with something that does not produce a hazard. For example, substituting the preparation of feed rations onsite to offsite would minimise the potential for feed related dust and would transfer the risk to somewhere else.

3.2.3 Engineered and other physical controls

The third most effective means of controlling hazards are engineered and other physical controls. These do not eliminate hazards but rather they isolate people and livestock from hazards. Capital costs of engineered controls tend to be higher than less effective controls in the hierarchy. However they may reduce future costs. "Enclosure and isolation" creates a physical barrier between personnel and hazards. An example is feedlot employees and contractors only working within air-conditioned tractors and other mobile machinery. Extraction fans can remove airborne dust from feed processing as a means of engineered control.

3.2.4 Administrative controls

Administrative controls are changes to the way people work. Examples of administrative controls include procedure changes, employee training, and installation of signs and warning labels. Administrative controls do not remove hazards, but limit or prevent people's exposure to them. For example, an administrative control to dust on feedlot access roads could be to limit traffic to those times of day when dust is rapidly dispersed, rather than late evenings when dust may remain at ground level and not disperse, i.e. due to a temperature inversion layer.

3.2.5 Personal protective equipment (PPE)

Personal protective equipment (PPE) includes gloves, respirators, hard hats, safety glasses, high-visibility clothing, and safety footwear. PPE is the least effective means of controlling hazards because of the high potential for damage to render PPE ineffective. Additionally, some PPE, such as respirators, increase physiological effort to complete a task and, therefore, may require medical examinations to ensure workers can use the PPE without risking their health. Dust masks are a form of dust PPE for feedlot employees and contractors.

3.3 Relative source contributions to feedlot dust

Dusty conditions are the result of a fine dry material becoming airborne. Feedlot pens and roads, combined with a lack of moisture, and dust agitation can create a dusty environment and hence, dust hazard. Animal activity in pens, pen maintenance, manure management, traffic on on-site roads and access roads, and feed storage and processing can all be dust sources.

Elimination or control, of either the fine, dry material or the air current (movement), means that dust can be eliminated or controlled, but control requires an understanding of the source of the dust. In this report, the sources of dust generation have been categorised as:

- Manure-related — animal activity, pen cleaning and manure management,
- Traffic-related — traffic on on-site and access roads, and
- Feed-related — feed storage and processing.

Various studies have investigated feedlot dust sources and different feedlots have different major dust sources. Huang *et al.* (2013) collected samples from a feedlot in Kansas and concluded that the largest contributor of dust was manure. Samples were analysed using Raman microscopy to identify that manure-related dust accounted for ≥ 60 % dust from the site (Huang *et al.* 2013). However, Wanjura *et al.* (2004) found that traffic-related dust was the major source of dust in a Texas feedlot. Dust emissions 10 µm or less in equivalent aerodynamic diameter (PM_{10}) were calculated and total emissions were in the range of 19 kg /1000 head/day. Of this, only 3 kg /1000 head/day was attributed to feedlot pen surfaces, with the remaining 16 kg /1000 head/day thought to originate from unpaved road surfaces (Wanjura *et al.* 2004).

Galvin *et al.* (2005) measured dust at an Australian feedlot using dust samplers located at various locations around the feedlot. Fig. 2 shows the contributions from different dust sources and indicates that:

- the roadway sites had the highest dust fall with the intermediate sites having the lowest;
- the roadway and background sites were highly variable with time; and
- the feedlot and intermediate sites were almost constant with time.

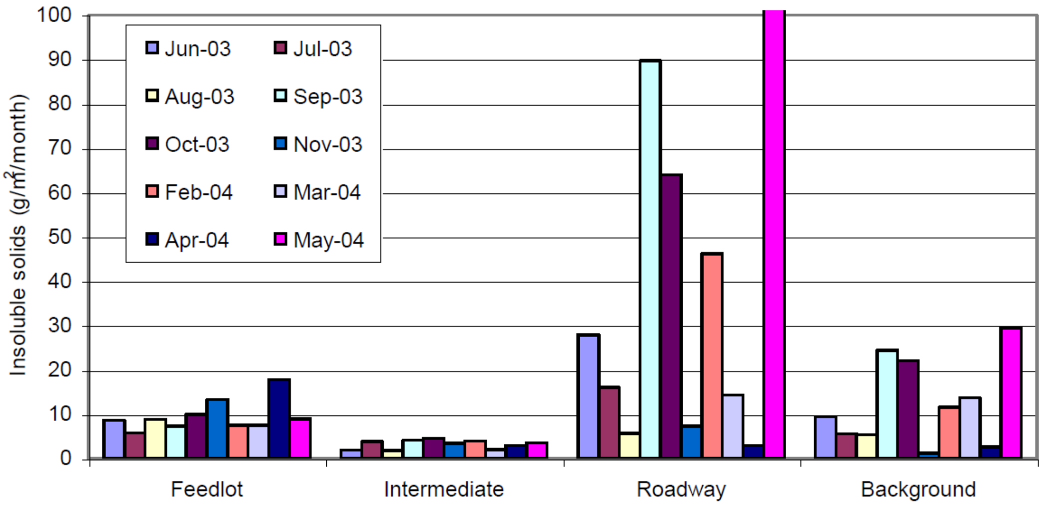


Fig. 2 – Dust contributions from different sources

It should be noted that in most studies that measure dust from feedlots, it is impossible to separate manure-related dust from other sources. Hence, these studies often describe dust from all sources as “feedlot dust”, not just manure-related dust.

These studies, and discussions with Australian lot feeders, indicate that:

1. Most Australian lot feeders consider feed-related dust to be a minor health risk, although workers tub grinding feed (i.e. hay) may be at risk.
2. The relative significance of manure-related dust versus traffic-related dust depends on site-specific circumstances. These circumstances include climatic conditions of the area (duration of summer or winter and seasonal rainfall), design stocking density and the current status of dust elimination options undertaken at a feedlot. For example, if all feedlot roads are sealed (bitumen), the lot feeder will recognise that manure-related dust is the major issue.

The significance of climatic conditions will be discussed in later sections.

3.4 Significance of time of day (atmospheric stability)

As with odour, the stability of the atmosphere strongly determines how dust will disperse after it becomes airborne. The stability of the ground-level air is categorised from Class A to Class F. Class A air occurs in bright, sunny days. Dust and odour is rapidly dispersed vertically. However, Class F stability occurs in early evenings and mornings. Odour and dust can be trapped in a temperature inversion. The odour and dust drifts away slowly and undiluted, often confined in valleys. Photograph 1 shows morning fog drifting downslope in an inversion layer. Hence, from a hazard viewpoint, the worse time to create dust is late evenings or overnight as the dust will not disperse. It will move undiluted away from the source towards receptors.

Photograph 1 – Morning fog caught in inversion layer (Class F stability)

4 Manure-related dust

4.1 Manure-related dust generation

At a feedlot, dust hazard from manure needs two elements for it to be present. They are:

1. A source of fine, dry matter with small particles of manure, and
2. A means for the dust to become airborne being either livestock, machinery or wind.

4.1.1 Source of manure-related dust

One of the major factors that affect dust emissions from cattle feedlots is the moisture content of the pen surface. If the moisture content is very low, dust problems might be expected. If the moisture content is relatively high, the dust emission rate and the resulting downwind concentration will be low. Research at a cattle feedlot in the U.S. suggested that a pen surface moisture content of about 20% (wet basis) may be the critical threshold for dust control (Bonifacio 2013; Bonifacio *et al.* 2015).

Low surface moisture (below 20%) occurs during dry weather conditions. Specifically, it occurs under prolonged periods when evaporation from the surface greatly exceeds moisture added to the surface, usually due to rainfall. Dry manure can occur at many sites around a feedlot. These include:

1. Production pens
2. Lanes and pens where cattle are handled
3. Manure processing areas

4.1.1.1 Dust from feedlot production pens

The action of cattle hooves causes dry manure to be broken down into fine particles. The moisture balance of the feedlot pad (pen surface) determines if the manure is dry and hence, dust will be created. Pad moisture content has other important implications for the environmental performance of cattle feedlots such as odour generation. Stocking density (number of cattle per unit of pen area) has a significant influence on pad moisture content. Every day, cattle add moisture to the pen surface via manure (faeces and urine) deposition. Fig. 3 shows the estimated moisture added to the pen surface each year for cattle of various weights kept at different stocking densities. This simple calculation assumes that cattle excrete 5% of their liveweight each day and manure is 90% moisture. Heavy cattle (750 kg) stocked at 10 m^2/head can add over 1200 mm of moisture per year (3.3 mm/day). During winter, this can exceed the evaporation rate (depending on location) and the pad remains wet. Under these conditions, odour problems are likely to develop. On the other hand, light cattle kept at 20 m^2/head contribute less than 1 mm of moisture/day. In summer, evaporation readily removes this moisture and dust can become a problem. Therefore, the choice of stocking density should achieve a balance between a pad surface that is too dry and one that is too wet. This is dependent on local climate, cattle size and other factors.

Following the USA example, the first feedlots in Australia stocked pens at about 10 m^2/head (about 110 ft^2/head). Experience in Australia has now shown that this stocking density is only appropriate in drier zones (annual rainfall <500 mm/yr). A stocking density of about 15 m^2/head is now considered more appropriate for feedlots in the main grain growing regions of Australia (e.g. Darling Downs) to achieve a balance between odour and dust generation.

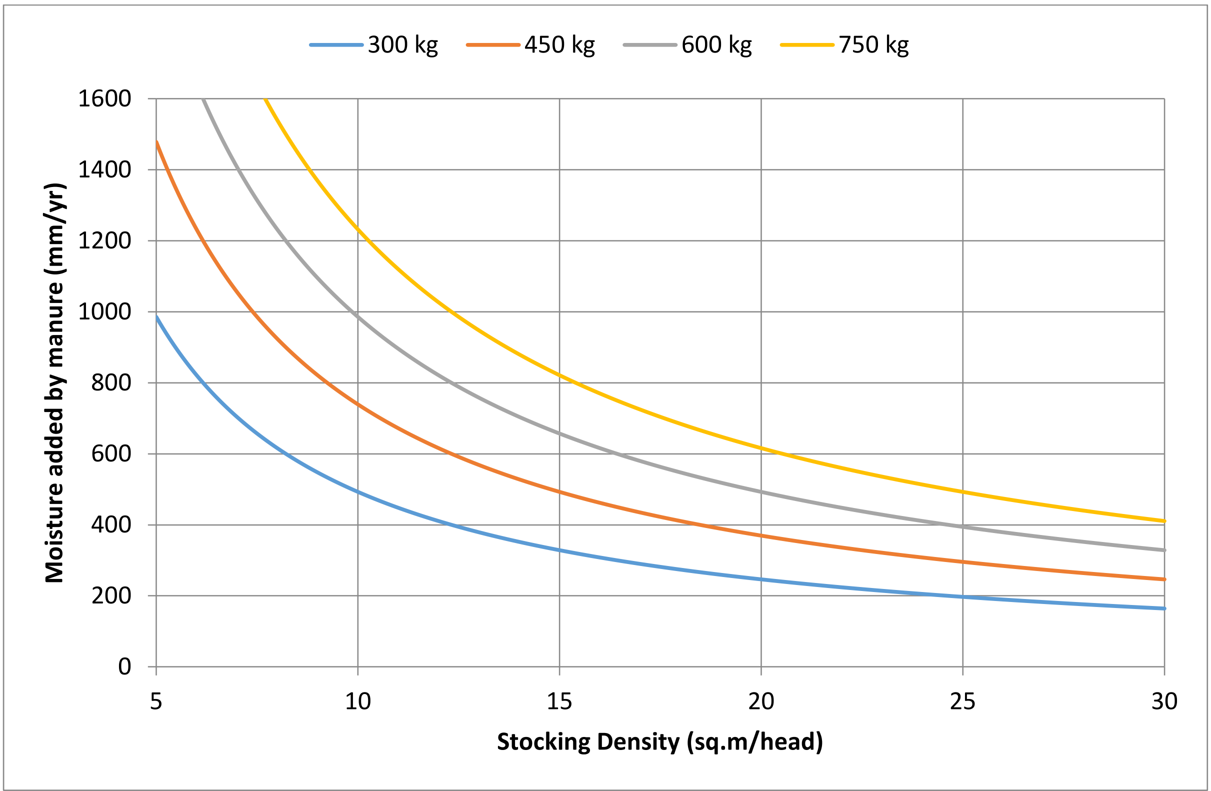


Fig. 3 – Estimated effect of stocking density on moisture added to pad surface

Figure assumes daily manure excretion of 5% cattle liveweight. Cattle liveweight was calculated based on various cattle weights and manure moisture content was assumed to be 90%.

Watts *et al.* (2014) analysed the distribution of feedlots in Australia versus annual rainfall (Table 1). In most guidelines, it is suggested that feedlots be located in areas with an annual rainfall of less than 750 mm to minimise odour. In 2012, there are 16% of individual feedlots in areas with less than 600 mm of annual rain but this is 26% of the current pen capacity. Unless a high stocking density is used, these feedlots could be prone to dust generation in pens.

Table 1 – Feedlot distribution vs. mean annual rainfall (2012)

	No. of Feedlots	% of Feedlots	Average Capacity	Pen Capacity	% Pen Capacity
Summary					
< 750 mm	629	74%	1940	1185809	88%
> 750 mm	225	26%	709	159636	12%
< 600 mm	137	16%	2579	353256	26%
600-649 mm	77	9%	1748	134569	10%
650-699 mm	176	21%	1953	343683	26%
700-750 mm	239	28%	1482	354301	26%
> 750 mm	225	26%	709	159636	12%
TOTAL	854	100%	1694	1345445	100%

Watts *et al.* (2014) also analysed the distribution of feedlots versus annual rainfall distribution. The distribution of rainfall throughout the year has a significant bearing on the management of a feedlot (Tucker *et al.* 1991). Feedlots located in areas with high winter rainfall and/or low evaporation rates are more likely to have problems with odour management, as a wet pad is the main cause of odour generation (Tucker *et al.* 1991). Problems also occur with cattle comfort and welfare as the pen manure remains wet and manure dags can attach to cattle. High evaporation and/or summer-dominant rainfall allows pens to dry more rapidly after rainfall. Hence, the period in which odour is caused is reduced and manure dags are less of a problem but dust can be a major problem in these zones.

Table 2 shows a summary of Australia's feedlots (2012) in relation to seasonal rainfall. Fig. 4 shows the current feedlot distribution with seasonal rainfall. In 2012, 22.5% of individual feedlots are located in winter-dominant or winter rainfall areas. This accounts for 27% of current pen capacity.

Table 2 – Distribution of feedlots in seasonal rainfall regions (2012)

Climatic Zone	No. of Feedlots	% of Feedlots	Average Capacity	Pen Capacity	% Pen Capacity
Winter Dominant	56	6.6%	1347	75404	6%
Winter	136	15.9%	2108	286718	21%
Total Winter	***192***	**22.5%**	**1727**	***362122***	**27%**
Summer Dominant	34	4.0%	1955	66472	5%
Summer	580	67.9%	1269	735932	55%
Total Summer	***614***	***72%***	***1612***	***802404***	***60%***
Arid	1	0.1%	400	400	<1%
Uniform	47	5.5%	3840	180499	13%
TOTAL	**854**	**100%**	**1895**	**1345425**	**100%**

Hence, while pen dust can occur during any dry period, it is mostly likely to occur in northern areas where summer conditions rapidly dry pens and in southern areas where winter-dominant rainfall means that pens are dry throughout the whole of the summer. Fig. 4 shows the distribution of feedlots across Australia for each seasonal rainfall zone. Both Table 2 and Fig. 4 agree; a high percentage of feedlots are located in the summer rainfall zone.

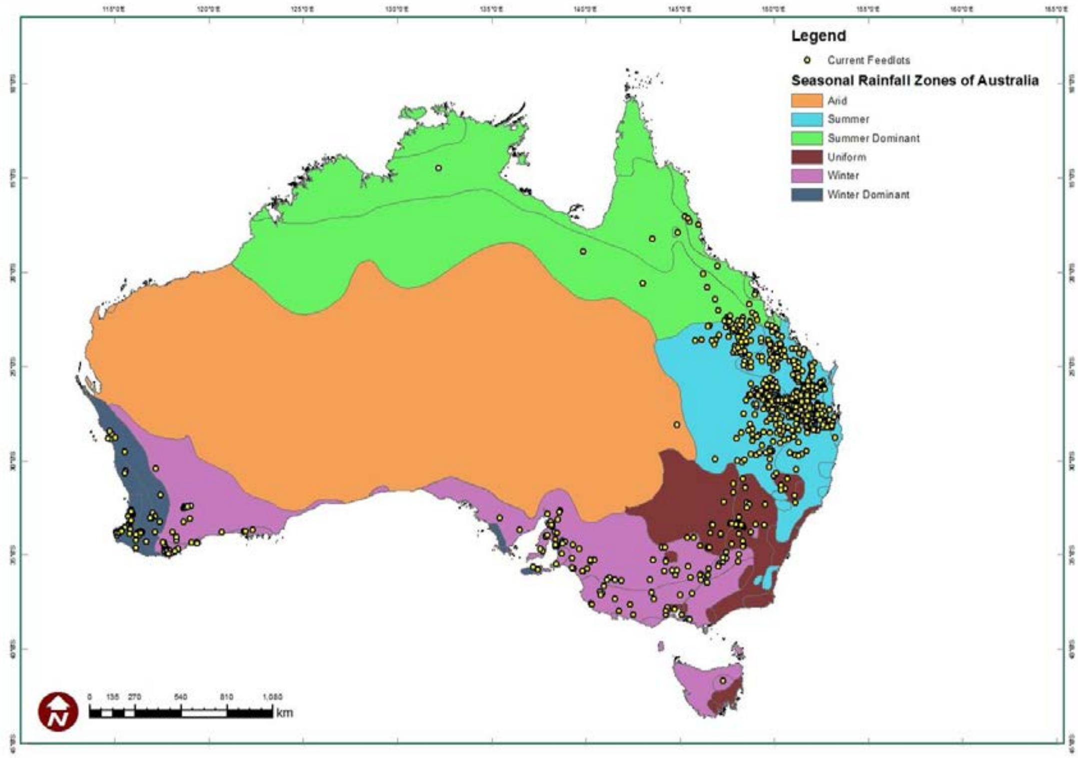


Fig. 4 – Feedlot location versus seasonal rainfall zone

Figure 5 shows real time PM_{10} concentrations over a two-day period at a feedlot in a summer rainfall zone (Galvin *et al.* 2005). This figure shows the typical peak in afternoon dust when cattle move about (see later sections) but it clearly demonstrates that a single rain event (6 mm) can produce adequate moisture to dramatically decrease the dust concentration.

The consequences of total annual rainfall and rainfall distribution has been assessed simplistically in Fig. 6, Fig. 7 and Fig. 8. In these charts, excess monthly moisture is mean monthly rainfall plus moisture added via manure less mean monthly Class A evaporation. In each case, moisture added by cattle is 51 mm per month taken from Fig. 3 assuming 600 kg cattle and 15 m^2/head stocking density. The winter-dominant zone is western Victoria. The summer zone is the Darling Downs and the summer-dominant zone is the Central Highlands of Queensland.

For the summer zone (Fig. 7), there is a slight moisture excess in winter and a moderate moisture deficit in summer. The variation in moisture deficit is from +20 mm to -90 mm per month which is relatively constant throughout the year.

However, for the winter-dominant zone, there is an excess of moisture from April to September which results in the pens remaining wet for the whole of winter. However, in summer, there is a moisture deficit of up 200 mm per month resulting in very dry pens. The variation in moisture deficit is from +65 mm to -170 mm per month, which is a substantially greater variation throughout the year compared to the summer zone. This means that, with a constant stocking density throughout the year, it is impossible to avoid dry, dusty conditions in summer if excessively wet pens are avoided in winter.

For the summer-dominant zone, with a 15 m^2/head stocking density, there is a moisture deficit all year round but this could be addressed by increasing stocking density for the whole year.

Although dry periods can occur at all sites, the worst pen dust conditions are likely to occur during summer in feedlots in winter-dominant rainfall zones and this analysis has been confirmed via discussions with several experienced feedlot managers.

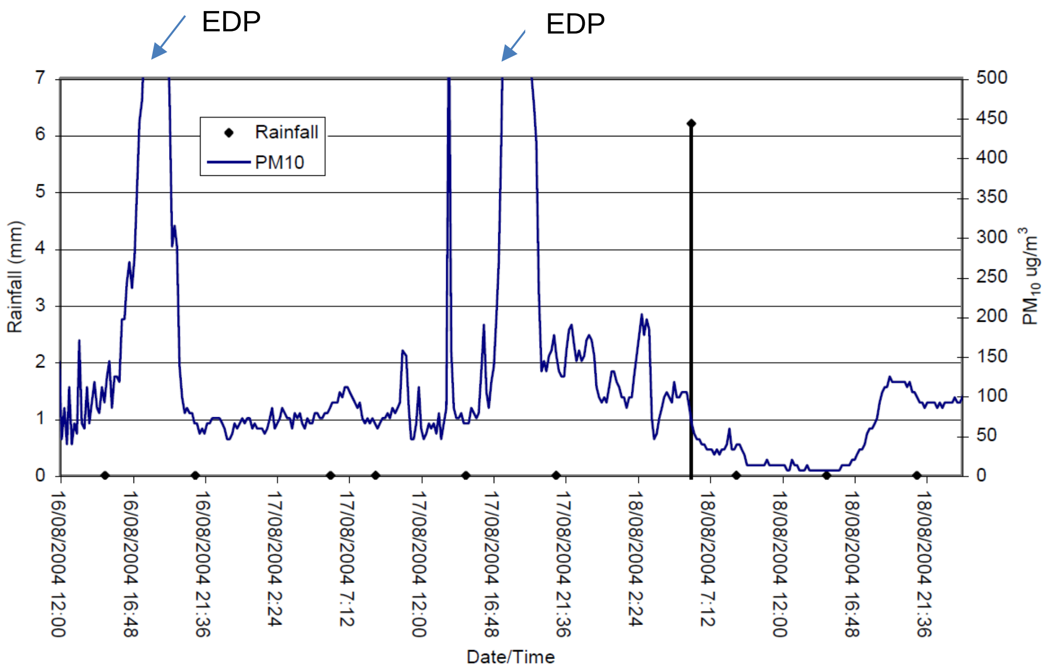


Fig. 5 – Real time PM_{10} concentrations and rainfall (Galvin *et al.* 2005)

Measurements taken from a feedlot in Southern Queensland with a holding capacity of 15,000 SCU. Measurements taken using a DustTrak 8520 real time PM_{10} analyser. Figure shows dust emissions are significantly increased during the EDP.

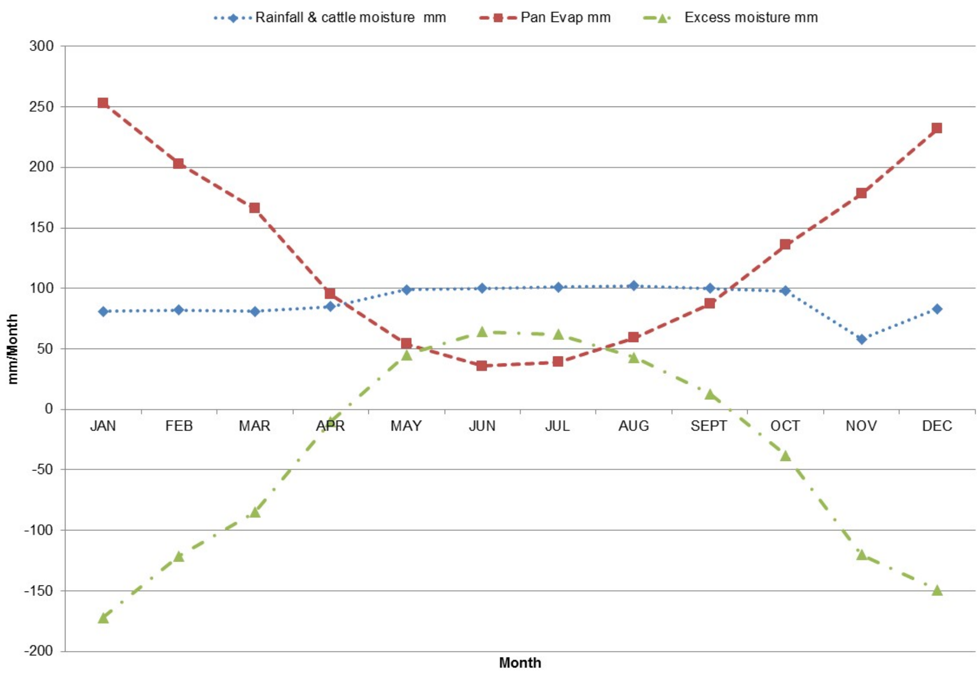


Fig. 6 – Simple pen moisture balance – winter-dominant rainfall zone

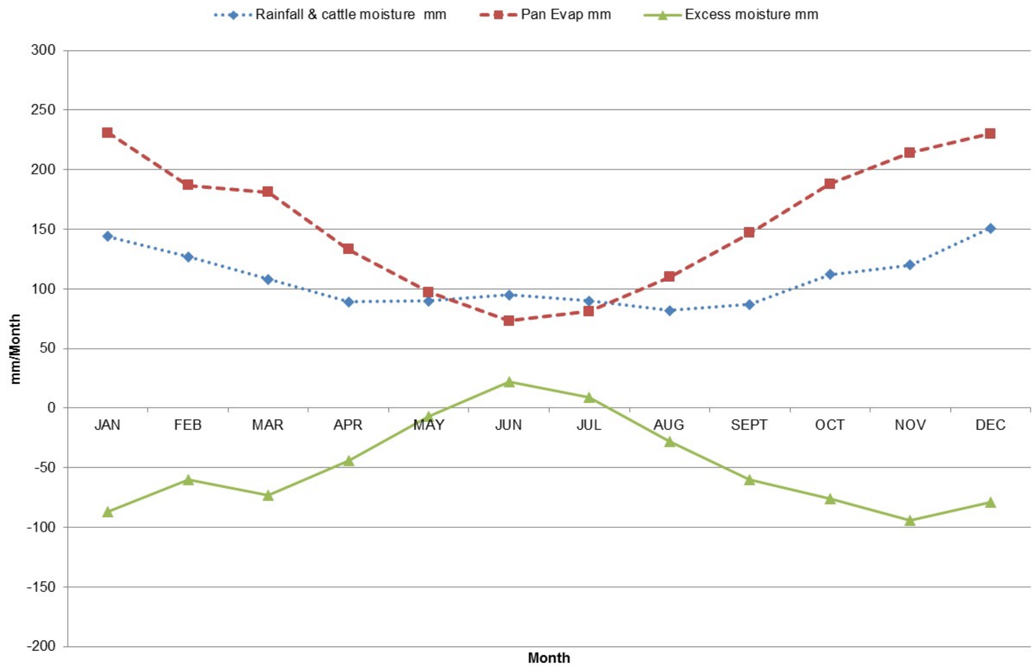


Fig. 7 – Simple pen moisture balance – summer rainfall zone

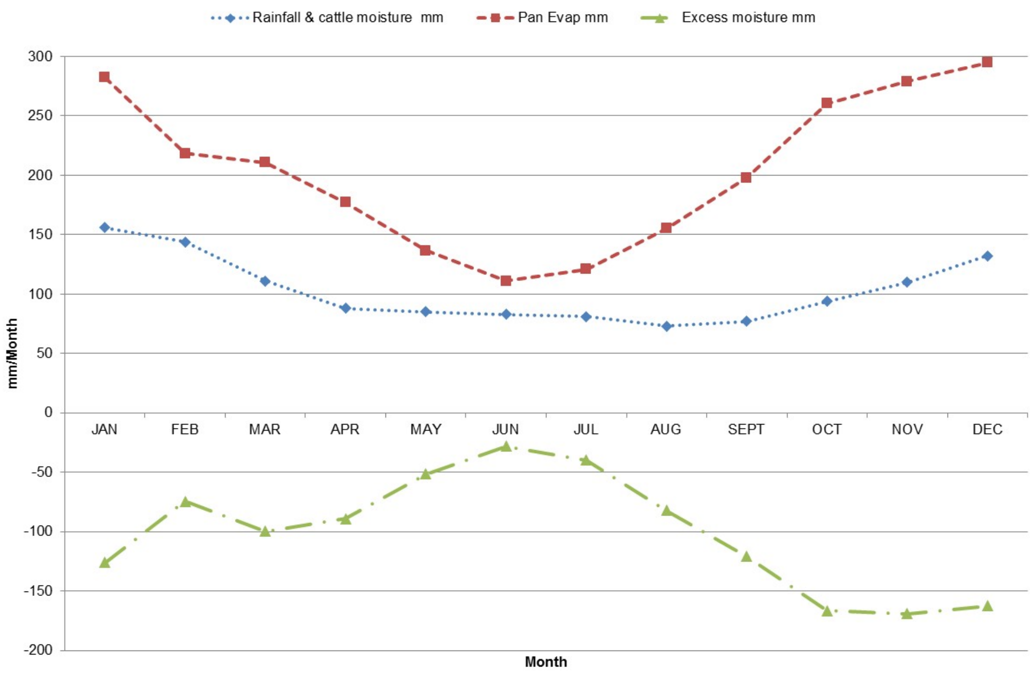


Fig. 8 – Simple pen moisture balance – summer –dominant rainfall zone

4.1.2 Creation of airborne manure-related dust

4.1.2.1 Feedlot pens

Manure-related dust becomes airborne mainly due to wind and cattle movement. Wind speed directly increases dust emissions through increased suspension of particulate materials but the impact is dependent on the time of day. Under windy conditions, dust generation is increased through the promotion of rapid evaporation from pen and road surfaces (Amosson *et al.* 2006), thereby increasing the potential for dust generation.

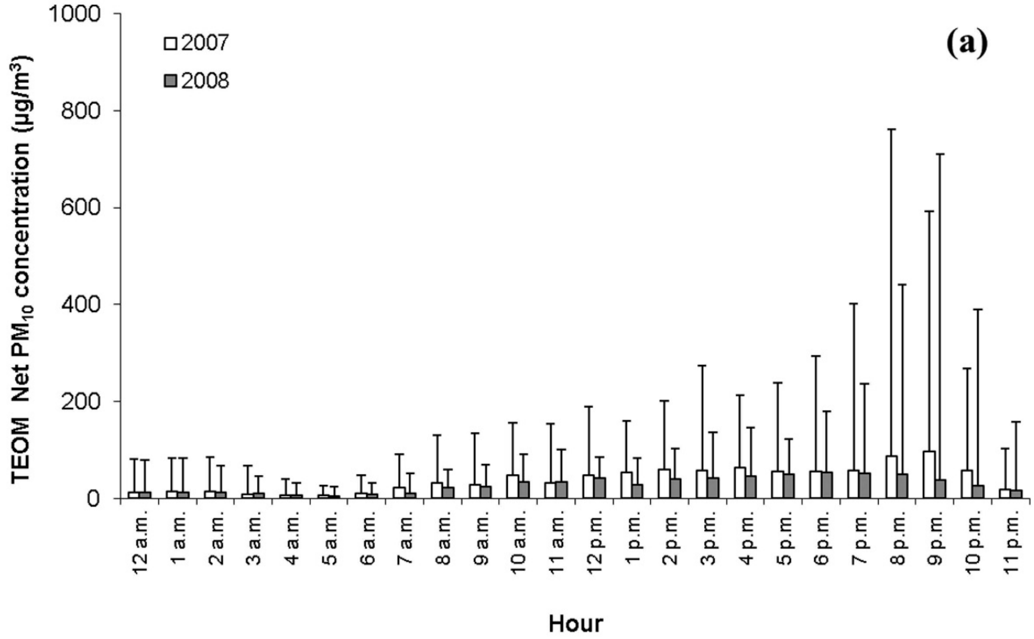
The generation of manure-related dust varies throughout the day, with typically lower levels in the early morning (e.g. between 2:00 am and 7:00 am as found by Bonifacio *et al.* (2012)) and higher levels in what is referred to as the evening dusk peak (EDP) (i.e. between 5:00 pm and 11:00 pm as found by Auvermann *et al.* (2003); Bonifacio *et al.* (2011); Bonifacio *et al.* (2012); Bush *et al.* (2014). Fig. 9 shows the daily dust generation pattern for two US feedlots. Increased animal activity levels, or animal play, are believed to be the significant contributor to the EDP.

This EDP phenomenon has been noted by Australian lot feeders and is seen in Fig. 5. In addition, feedback from some Australian lot feeders suggests that there is also a lesser dust peak after feeding when cattle become a little more active.

Daily PM_{10} concentrations are similar (≤ 200 μg/m^3, Fig. 9) during the day and at night. A significant increase in concentration occurs late each afternoon (maximum value of ≈5000 μg/m^3). The afternoon rise is most likely associated with increased cattle activity as ambient temperatures drop following daytime heating and the cattle begin to move about the pens (Sweeten *et al.* 1998).

Fig. 10 illustrates the median hourly net PM_{10} concentrations for two commercial feedlots in Kansas, measured over a two-year period (Bonifacio *et al.* 2012). A lull in dust levels can be seen in the early hours of the morning and an EDP is observed from 8:00 pm to 9:00 pm. Interestingly, times of peak dust concentrations (8:00 pm to 9:00 pm) do not correspond with times of maximum dust emissions (measured as mean hourly PM_{10} emission flux), (Fig. 9). Maximum dust emissions were recorded in the afternoon period between 12:00 pm to 4:00 pm. Emission flux data suggests that animal activity may be quite high in the afternoon period, since animal activity is a significant mediator of dust emissions.

Bonifacio (2013) concludes that maximum dust concentrations are a combination of three factors, being, high emission rate, low wind speeds, and/or stable atmosphere. All three conditions were found present during the EDP, and this corresponded to maximum dust concentrations (Fig. 9). Emission rates during the afternoon were highest, although atmospheric conditions tended to be unstable, resulting in reduced dust concentrations. Conversely, during the early morning period, atmospheric conditions tended to be stable, although emission rates were low, which also resulted in reduced dust concentrations.



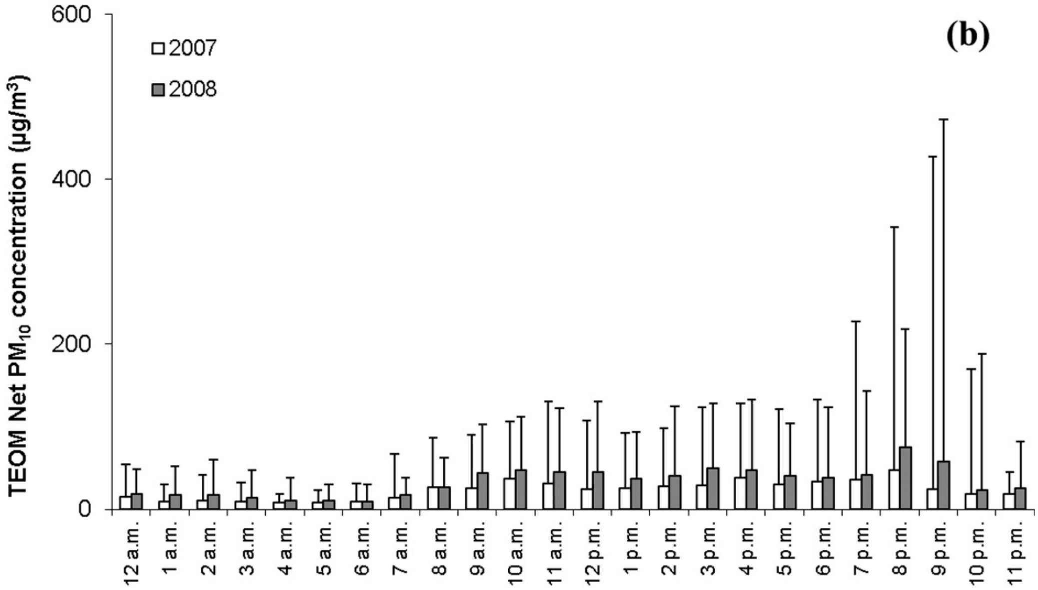


Fig. 9 – Median hourly net PM_{10} concentrations for two feedlots (a and b)

Notes: Error bars represent upper standard deviation estimates. Measured with a tapered element oscillating microbalance (TEOM) PM_{10} monitor. Net concentrations are calculated by subtracting upwind concentrations from downwind concentrations.
Source: Bonifacio *et al.* (2012), p. 356

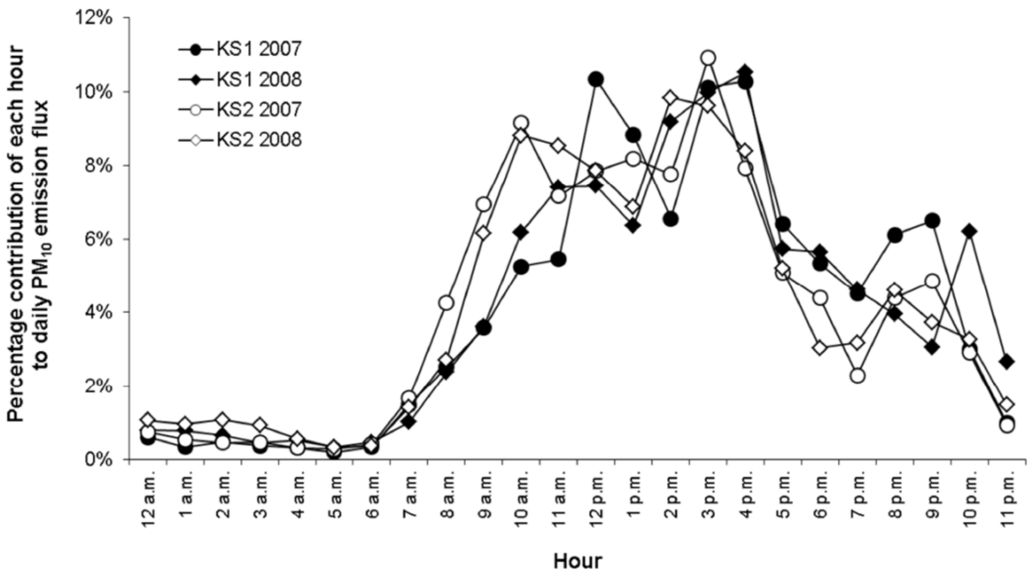


Fig. 10 – Percentage contribution of each hour to the daily PM_{10} emission flux for feedlots KS1 and KS2 based on mean hourly PM_{10} emission fluxes for the 2-yr period using days with emission data (Bonifacio 2013)

4.1.2.2 Cattle handling and processing

Manure-related dust can also become airborne when cattle are moved around the feedlot. Photograph 2 and Photograph 3 show dust creation due to the movement of cattle. Very little moisture is added to the surface of lanes and holding yards due to limited manure deposition so these areas can become dry quickly. Furthermore, movement of livestock breaks up the manure into small fine particles and causes it to become airborne. Unlike dust generated in pens which occurs in late afternoon when cattle become active, dust from lanes and cattle handling facilities occurs when cattle are moved (at a time of day determined by management). Time of day becomes a factor in the choice of dust mitigation strategies.

Photograph 2 – Dust around a cattle handling area

Photograph 3 – Dust generated by moving cattle

4.1.2.3 Manure Management

Manure-related dust can also become airborne during manure management activities including pen cleaning and manure handling in the manure stockpile area. Photograph 4 and Photograph 5 show manure management activities (manure screening and manure spreading). As with all dust issues, manure moisture content is important but, as with cattle handling, choice of the time of day becomes a factor in the choice of dust mitigation strategies.

Photograph 4 – Manure composting and screening area

Photograph 5 – Dust generated during manure spreading

4.2 Components of manure-related dust

Manure-related dust contains a range of constituents that have different generation, dispersal, and impact characteristics. It is a complex mix of organic and inorganic particles. Faeces and urine is excreted by the cattle. This is ground into a fine powder by cattle activity and is mixed with the substrate that forms the pad of the pen. Bedding, hair and skin scurf adds to the components of manure-related dust. Insects contribute insect parts and mites. The soil component of the dust contributes fungi, bacteria and toxins (glucans, mycotoxins and endotoxins) (Wilson *et al.* 2002).

Perillo *et al.* (2009) used energy-dispersive X-ray microanalysis on slaughterhouse collected lung samples to identify a wide range of elements in cattle lung tissue, including silicon, aluminium, titanium, iron, carbon and small amounts of other metals. The same kinds of metals were found in bronchial and mediastinal lymph nodes with differing levels of distribution. Presumably, these elements were derived from the dust inhaled by the cattle.

Hence, manure-related dust contains:

1. Fine particulate matter (PM)
2. Nutrients derived from manure (N, P, K)
3. Other chemical compounds
4. Biological matter.

In terms of human and livestock health, harmful manure-related dust constituents include steroids, hormones, microorganisms (i.e. bacteria and fungi) and endotoxins (i.e. toxins inside bacteria that are released when the bacteria disintegrate). Further information on potential antibiotics and antibiotic resistance genes can be found in Section 4.2.5.3.

4.2.1 Particle size distribution (PSD)

The fine particles in dust are characterised by their particle size distribution (PSD). PM_{10} is particulate matter 10 µm or less in equivalent aerodynamic diameter. $PM_{2.5}$ dust is a finer sized fraction and is 2.5 µm or less in equivalent aerodynamic diameter. By way of comparison, a human hair is approximately 100 µm, so roughly 40 $PM_{2.5}$ dust particles could be placed across a hair's width. According to the US EPA, Total Suspended Particulates (TSP) comprise particles with equivalent aerodynamic diameters of 100 µm or less, and US EPA reference method 40 CFR 50 requires TSP samplers to collect all suspended particulates within this range.

Meat and Livestock Australia (2005) conducted a comprehensive study of dust emissions from a beef cattle feedlot on the Darling Downs in Queensland. Dust fall was monitored from 17 sites in and around the feedlot over a twelve-month period. Although the report concluded that nuisance dust to the community is unlikely to be an issue, the proportion of fine dust less than or equal to 10 µm (PM_{10}) was quite high, representing 59% of total TSP. This is significantly higher than the published 20-40% proportion of PM_{10} dust reported from US feedlots (Galvin *et al.* 2005). PSD of dust emissions has important implications for human and animal health and Galvin et al.(2005) recommended that further studies on PSD be undertaken for Australian feedlots. This may be especially true for PSD downwind from feedlots where standard monitoring practices using TEOM and FRM (US federal reference method) samplers are likely to result in sampling bias (Auvermann 2016) (see Appendix A).

4.2.2 Measured feedlot dust emission rates

Daily particulate matter, PM_{10}, emission factors (defined as mean PM_{10} emission rates) for beef cattle feedlots are in the range of 4.6–127 g/animal/day and are highly variable (Parnell 1994; McGinn *et al.* 2010; McEachran 2015). Emission factors allow for the calculation of total dust emissions from cattle feedlots, although due to the high variability in emission factors, these calculations tend to be inaccurate. Differences in measured PM_{10} emission factors may partially relate to differences in dust monitoring techniques, leading to complications when comparing feedlot dust emissions. Dust measurement techniques need to be standardised for the generation of reliable monitoring data.

In 1972, it was estimated that emissions from the US beef cattle lot feeding industry constituted 0.11 % of total TSP emissions, equating to an estimated 20,500 metric tonnes (US EPA 1977). In the US, agricultural operations such as beef cattle feedlots are typically classified as being minor sources of particulate air pollution (PM_{10}) (Wanjura *et al.* 2004), although dust emissions can still be significant (WSDE 1995; Cole 2008).

4.2.3 NPI Feedlot dust estimation rates

Even though the dust from the feedlot is the major source of PM_{10} emissions, (Department of the Environment 2007) reporting for PM_{10} (and all category 2 substances) is only triggered by fuel usage (Department of the Environment (2007), p. 20). The reporting requirements to the NPI for particulate emissions for other industries (i.e. mining and quarrying) appear in-line with intensive agriculture.

The NPI calculates PM_{10} dust emissions using a dust emission factor of 11.7 kg PM_{10} dust /SCU/year. NPI reporting does not currently use emission factors for $PM_{2.5}$ particulates, although $PM_{2.5}$ reporting is carried out for fuel combustion. Dust emission factors for Australian NPI reporting requirements are different from the emission factors used in the US. In the US, the AP-42 emission factor for cattle feedlots is 127 kg d^{-1} per 1,000 head of capacity (U.S. EPA 1986.) as cited in Romanillos and Auvermann (1999). Accepted US emission factors are equivalent to an emission factor of 46.36 kg TSP/SCU/year, and US EPA PM_{10} emission factors are equivalent to 17 kg PM_{10} dust /SCU/year.

4.2.4 Chemical components of manure-related dust

Manure-related dust contains a range of constituents with different generation, dispersal, and impact characteristics. Huang *et al.* (2013) found Raman microscopy could differentiate between manure-related dust, and dust originating from other sources. Manure-related dust characterization was based on the source material, being fresh manure samples, rather than the dust itself. No references could be found that provided a full chemical analyses of feedlot dust. As an approximation, it should be similar to pen manure analyses but this has not been confirmed.

4.2.5 Biological components

Manure-related dust can contain a wide range of biological components. Some are present in the manure when excreted, others grow in the manure and feedlot pen surface. Compounds such as hormones, micro-organisms and endotoxins are all found within dust generated from manure.

4.2.5.1 Active steroids

Hormones and steroids that have been found in feedlot dust include:

- estrogens such as estrone and estradiol (female hormones);
- androgens (male hormones),
- trenbolone and trendione (anabolic steroids); and
- melengestrol acetate which is a steroidal progestin used as a growth promoter in animals (e.g., Blackwell *et al.* (2011); Blackwell *et al.* (2013) as cited in Wooten *et al.* (2015) .

In-vitro testing of cultures from feedlot dust have tested androgens and estrogens listed above from downwind sites (found in 52% – 100% of samples) compared with the much lower frequency (0% – 10%) in upwind samples (Wooten *et al.* 2015). The results from individual feedlots varied somewhat, with no identifiable pattern relative to weather, but less PM was generated by smaller feedlots (Wooten *et al.* 2015). Analysis of five US feedlots by Blackwell and colleagues (2015) detected estrogens (17α-estradiol and estrone) in the majority of their samples (94%), finding median concentrations of 20.6 ng/g for 17α-estradiol and 10.8 ng/g for estrone. Blackwell *et al.* (2015) also found Melengestrol acetate (31% of samples; median concentration 1.3 ng/g) and 17α-trenbolone (39% of samples; median concentration 1.9 ng/g).

Other androgens that may occur in feedlot dust include testosterone, epitestosterone (Angeletti *et al.* 2006), as cited in Wooten *et al.* (2015), and androstenedione (Bartelt-Hunt† *et al.* 2012), as cited in Wooten *et al.* (2015). In addition to these manure-based steroids, non-cattle sources such as feed and diesel engine exhaust have also been found to yield phytoestrogens, which act similarly to estrogens (Owens *et al.* 2006; Noguchi *et al.* 2007), as cited in Wooten *et al.* (2015). While the effects of these compounds have been identified under laboratory conditions and found to be endocrine active (i.e. able to interact or interfere with normal hormonal action), these analyses are likely to overestimate the exposure potential for humans and animals due to the chemical extraction processes used, which is unlikely to be as efficient in natural biological systems (Wooten *et al.* 2015). Recent research suggests that overall risks associated with steroidal hormones in Australian feedlot manures are low to negligible, even under high exposure scenarios (Roser *et al.* 2011b). Risk analysis included the investigation of 13 endocrine disrupting compounds, including estrogens, androgens, progestins and anabolic steroids. Individual hormone risk ratings for different exposure scenarios were further provided in the report (Appendix 36, pages 696 to 699) (Roser *et al.* 2011a).

4.2.5.2 Microorganisms and endotoxins

Wilson *et al.* (2002) subjected feedlot cattle dust particles 2.5 µm or less in diameter to microbiological examination. Only gram-positive bacteria that were considered non-pathogenic to the bovine respiratory system were cultured. All of the fungi recovered were considered to be non-pathogenic. A more recent study by Purdy *et al.* (2004) found 18 genera of gram positive bacteria and no gram-negative bacteria. The most numerous fungi that were isolated are extremely common fungi found on dying and dead plant substances. These fungi have also been found in granary dust (Domsch and Gams 1972; Palmgren *et al.* 1983).

Manure contains a large content of gram-negative bacteria. However, when the manure is subjected to high temperatures, UV radiation and desiccation, the viability of these bacteria is affected (Chang *et al.* 1985; Marthi *et al.* 1990). Chang et al. (1985) found that UV radiation can lead to a 99.9% inactivation of cultured vegetative bacteria, although viruses, bacterial spores and amoebic cysts require increased UV radiation doses for effective inactivation.

When manure becomes dry, it produces dust particles that contain endotoxins that originate from the gram-negative bacteria (Purdy *et al.* 2002c). Endotoxins are relatively heat stable, biologically active material that profoundly affects humoral and cell-mediated immunity when injected parentally (Burrell 1990). A study by Purdy *et al.* (2004) found significantly more bacteria in dust in summer and found increased concentrations of endotoxin in winter. These gram-positive bacteria are not bacteria considered significant in the Bovine Respiratory Disease (BRD) of feedlot cattle. They concluded that the presence of endotoxin may be a significant issue in regard to animal health.

The endotoxin and microorganism content of dust from 241 intensive livestock buildings in Europe was analysed by Seedorf (1998). Intensively-housed beef cattle were found to have low endotoxin levels measured as µg exposure per hour (µg /h). Exposure rates were 3.7 µg/h (500 kg liveweight) mean inhalable endotoxin and 0.6 µg/h (500 kg liveweight) mean respirable endotoxin. This compares favourably with poultry broiler sheds (817.4 µg/h, and 46.7 µg/h, respectively) and piggery sows (37.4 µg/h and 3.7 µg/h, respectively), with higher levels during the day than at night, and for young beasts than mature animals (Seedorf 1998). Total bacteria counts were also lowest for cattle (4.3 log CFU/m^3) compared with poultry houses (6.4 log CFU/m^3) and piggeries (5.1 log CFU/m^3), although fungi concentrations were similar for all three livestock types: 3.8 log CFU/m^3 for cattle, 3.7 log CFU/m^3 for pigs, and 4.0 log CFU/m^3 for poultry (Seedorf 1998). These differences in microbial and endotoxin levels may be due to many factors, including source factors such as animal health and activity levels; as well as clearance rates through ventilation and settlement (Seedorf 1998).

More recent studies of piggery (Sowiak 2012) and dairy (Funk 2011) airborne particulates found somewhat similar levels of microorganisms to that of Seedorf and colleagues (1998) study, with dust from 13 piggeries containing an average of 5.5 log CFU/m^3 bacteria (48% respirable) and 3.4 log CFU/m^3 fungi (69% respirable); but slightly lower bacteria levels in the single dairy's particulates (3.5 log CFU/m^3 in summer, 3.8 log CFU/m^3 in winter).

4.2.5.3 Antibiotics and antibiotic resistance genes

In addition to the pathogenic potential posed by the microbiota themselves, airborne feedlot particulates have also been found to transport antibiotic resistant genes within these microorganism communities, as well as directly transporting antibiotics such as those found by McEachran and colleagues (2015): tetracycline group of antibiotics (found in 60 % of samples), including chlortetracycline, tetracycline and oxytetracycline; as well as monensin and tylosin. Oxytetracycline was the most prevalent, (found in 100% of samples), and had a mean concentration of 820 ng/g (McEachran 2015). However, monensin was found in the highest concentrations, with a mean of approximately 1800 ng/g (McEachran 2015). Chlortetracycline was found with mean concentration of 970 ng/g; while tetracycline at 280 ng/g, and tylosin at approximately 300 ng/g, had the lowest concentrations (McEachran 2015). Based on reported persistence (half-life decay) data, McEachran and colleagues (2015) estimate that active forms of these antibiotic compounds may persist through airborne transport and deposition onto soil, water or other surfaces from days to weeks.

McEachran and colleagues also investigated the abundance of antibiotic (tetracycline) resistant genes in feedlot PM from 10 US feedlots. They found mean increases in gene copies (across six resistant genes) downwind of the feedlots compared with upwind samples of less than 200-fold for TetL gene; between 1000- and 2000-fold for TetL, TetO, TetW and TetQ genes; and over 3500-fold for TetM gene (McEachran 2015).

The McEachran (2015) paper received lots of attention from the lot feeding industry, and a recent press release by Apley *et al.* (2015) expressed concerns about the research findings. In particular, it was noted that the qPCR techniques used by McEachran (2015) only reveal the presence of bacteria, not their viability. In this regard, the research does not indicate the presence of any viable bacteria in the particulate matter samples analysed. Secondly, it was concluded that the non-viable bacterial cells found do not pose a direct risk to human health. Concentrations of antimicrobials bound to PM would also be reduced due to atmospheric dispersion and dilution, and this is not discussed in the paper, hence more research is needed. Research by O’Connor *et al.* (2010) also found few associations between measures of human disease and proximity to intensive livestock facilities.

4.3 Impacts of manure-related dust

4.3.1 Impacts on livestock

Dust inhaled by livestock may contribute to respiratory disease or a general decline in animal welfare. This section discusses the impact of manure-related dust on livestock.

4.3.2 Bovine respiratory disease (BRD)

4.3.2.1 BRD prevalence

The United States Department of Agriculture (USDA) National Statistics Service (USDA 2011b) records mortality statistics for cattle and calf losses in America. The latest statistics show respiratory-related illness, labelled as BRD, was the cause of 1.06 million cattle deaths in 2011 (USDA 2011a). This represents more than a quarter of total cattle and calf losses for 2011 (3.99 million head) (USDA 2011a) and makes respiratory related illness the leading cause of cattle and calf loss. It is difficult to establish the most significant factors involved in contracting BRD, although immunosuppressed cattle are of greater risk to contracting disease. Immunosuppression may occur due to stress, particularly when cattle are transported in close confinement or when held in holding pens (Taylor *et al.* 2010; Hay *et al.*

2014). Viral transmission is increased due to co-mingling with cattle from other properties and can be increased by the harmful effects of respiratory dust emissions (Yu 2012).

Perkins (2013) provided a comprehensive animal health survey of the Australian feedlot industry for 2010. The annual cost of all pulls and deaths was estimated to be $50 million dollars per year, and was calculated to be equivalent to a cost of about $22,000 per 1000 head turned off (Perkins 2013).

4.3.2.2 The effect of dust on animal health

The inhalation of dust has always been considered to be a predisposing factor in the pathogenesis of BRD in feedlot cattle. There are a number of hypotheses which try to explain the mechanisms by which the inhalation of dust predisposes feedlot cattle to the development of BRD. The lower respiratory tract is constantly being exposed to bacteria which are inhaled on dust particles. Most of these particles have some impact on the respiratory mucosa and are rapidly removed or inactivated by pulmonary clearance mechanisms. Particles greater than 2 µm in diameter are removed by the “mucociliary apparatus” or “mucociliary elevator”. This apparatus is a mucus layer produced by cells in the respiratory epithelium which lines the nasal passages, trachea, bronchi and bronchioles. This mucus layer and the associated ciliated respiratory epithelial cells collectively form the “mucociliary apparatus”. The mucus together with the inhaled bacteria that have been trapped, as well as inhaled debris are propelled to the oropharynx by the beating cilia, where they are swallowed (Hjerpe 1993). The cough reflex is important in assisting in the removal of large particles from the trachea and major bronchi. One hypothesis implicating dust in the development of BRD is that this “mucociliary elevator” is severely damaged or overwhelmed by constant bombardment of irritant dust particles, this irritation damages the ciliated respiratory epithelia such that the mucus and debris is not moved to the oropharynx but instead this exudate gravitates down the trachea, into the bronchi and bronchioles eventually settling in the alveoli of the dependent ventral aspects of the lung. These dependant parts of the lung, in particular the cardiac lobe, cannot drain and so fill with exudate creating a suitable environment for the rapid proliferation of bacteria especially *M. Haemolytic* and *P. multocidia.* The IBR (Infectious Bovine Rhinotracheitis) virus precipitates this process by invading the epithelial cells of the upper airways damaging the epithelial cilia and causes and overproduction of mucus by the animal in response to this infection.

A second hypothesis is that small dust particles, ranging in size from 0.5 to 2 µm in diameter, with their accompanying bacteria and endotoxins, reach the alveoli and impact on the alveolar surface fluid film. These particles are rapidly phagocytized primarily by pulmonary alveolar macrophages, a component of the innate immune system (Hjerpe 1993). However, in circumstances where the clearance mechanisms are overwhelmed or fail to function the bacteria are able to proliferate and respiratory disease progresses.

Efficiency of the mucociliary elevator may be adversely affected by systemic dehydration, cold air, irritant gases, and respiratory viruses. Pulmonary alveolar macrophage function may be affected by starvation, systemic acidosis, cold air, hypoxia, treatment with glucocorticoids and stress (Hjerpe 1993). Dust has been considered to be a major environmental stress on cattle depressing immune function which enables pathogens to proliferate in the respiratory tract.

A search of the scientific literature has been embarked upon to find evidence to support the hypothesis that feedlot cattle exposed to feedlot dust can cause respiratory disease. MacVean *et al.* (1986), suspected that inhalation of dust particles 2-3.3 µm in diameter was associated with an increased incidence of pneumonia in cattle 16-30 days on feed in a Colorado feedlot. Other meteorological parameters were also implicated in the development of respiratory disease in this study. This was an observation study with no control groups and the conclusions were associative. However, Smith (2007), in a controlled study using aerosolized dust which mimicked the range of dust particle size used in the MacVean study did not find any difference in the health parameters measured in the calves.

There was no evidence in the scientific literature examined that supports the hypothesis that dust particles cause physical damage to the mucociliary apparatus. However, there was no evidence to disprove this theory either. The review did not find any research that has been done to examine the effects of dust on the upper respiratory tract of feedlot cattle and what changes if any occur to the anatomy and function of the mucociliary apparatus.

4.3.2.3 Effect of aerosolised dust on the health and performance of feedlot cattle

The second hypothesis on how dust affects feedlot cattle is that small dust particles, less than 2.0 µm, reach the alveoli in such concentrations that the phagocytosis clearance mechanisms are overwhelmed and bacteria multiply leading to the progression of respiratory disease.

The studies that have been described earlier have shown that only gram positive bacteria are able to be cultured from feedlot dust, and those cultured are non-pathogenic. To support the hypothesis a different mechanism must be occurring. Chirase *et al.* (2004) conducted a study in which young Spanish goats were exposed to ground feedlot manure of 0.89 to 356 µm (mean 100 µm) particle size, aerosolized and blown into a canvas tent for four hours per day for 21 days to simulate chronic dust events. The feedlot dust contained 27 µg of endotoxin per gram of dust. One group of goats was treated with tilmicosin phosphate (10 mg/kg BW, S.C.) prior to starting the study. The results showed no difference in final body weight or feed intake in either dust treated or tilmicosin phosphate plus dust treated animals. There was no difference between the feed intake, ADG (average daily gain) and final body weight between dusted and the non-dusted control groups. The gain : feed (G:F) ratio was higher ($P<0.05$) in the dust treated goats.

The study showed that goats treated with tilmicosin phosphate had greater G:F ratio ($P<0.05$), than untreated goats. Throughout the study, the tilmicosin phosphate treated goats outperformed the goats that were not exposed to dust. However, when goats were treated with tilmicosin phosphate prior to chronic dust exposure events, the tilmicosin did not improve ADG ($P>0.05$). A similar study by Chirase *et al.* (2000) using market stressed steer calves showed a significant difference ($P<0.05$) in the steers treated with tilmicosin phosphate prior to dust exposure for ADG over the group not treated with tilmicosin phosphate. The feed consumption of the steers exposed to the dust was 20% lower than those not exposed to dust. In the study by Chirase *et al.* (2004), goats exposed to one or more dust events had higher rectal temperatures ($P<0.002$) at 4 and 8 hours post the dust event. The rectal temperatures did not differ however, ($P>0.05$) in any measurement after 12 hours post dusting. This suggests that the fever produced by a single dust event is temporary and Purdy *et al.* (2002b) suggests that this change in rectal temperature may be due in part due to endotoxin in the dust. In this study, goats exposed to dust showed a 30% increase in serum fibrinogen, this was 10 times that of the control goats ($P<0.03$) 4 hours after exposure. There was no differences in serum fibrinogen ($P>0.05$) after any other dusting events. No effect from tilmicosin phosphate treatment was observed and no difference ($P>0.05$) in serum fibrinogen was observed between the dust treatment group and those not exposed to dust in the chronic dusting phase of the study.

Packed cell volumes and blood haemoglobin concentrations were lower ($P<0.05$) at 44 and 210 hours after the first dust event. However, during the chronic dust exposure period no differences were found ($P>0.05$) between the dust treatment groups. The total white blood cell (WBC) counts were higher at 12 hours ($P<0.07$) and 20 hours ($P<0.02$) for the dust exposed group compared with the control goats. Similarly, in goats that receive chronic dust exposure the WBC was significantly higher for all hours on the first day when compared with the control group. However, on all other days measured, the WBC counts were not different ($P>0.05$)

between dust exposure treatments. This suggests that there is an adaptation that occurs within the immune system to repeated exposure to dust or endotoxin (Purdy *et al.* 2002c). Total blood lymphocytes were increased ($P<0.02$) compared with the control animals. Chirase *et al.* (2004), suggested that the changes in the number of blood lymphocytes within 210 hours after a single dust event could be due to an actual increase in cell number, cell distribution or repartitioning of cells within tissues. During the chronic dust phase, no differences ($P>0.05$) were detected in blood lymphocyte counts between dust treatment groups. This suggests that the blood lymphocyte changes were temporary. Blood eosinophil count changes were similar to the blood lymphocyte response.

The review of the literature could not find any research specifically examining the effects of dust as a stressor. Some studies, such as Purdy *et al.* (2002a); Purdy *et al.* (2002b); Purdy *et al.* (2002c); Smith (2007), examined the stress effect indirectly by examining fibrinogen and in some cases haptoglobin concentrations, following dust treatment. Fibrinogen is an indicator of inflammation and haptoglobin an indicator of a response to stress. Smith (2007), measured fibrinogen concentration, and did not find any difference between treatment and control groups. Purdy *et al.* (2002a) found no difference in fibrinogen concentrations between the tilmicosin treated animals and the non-treated animals following one dust treatment. Overall, the results for changes in fibrinogen concentration were inconsistent. None of the studies found in the literature consistently showed a significant increase in fibrinogen concentration across groups treated with dust regardless of the number of dust exposures, though all studies with the exception of Smith (2007), shown some groups at different exposure levels showing differences, often only numerical, from the control groups. This finding was not in the majority of dusted groups and therefore the effect of dust on fibrinogen concentrations is equivocal. Haptoglobin concentrations were not significant different following dust treatment in any of the available studies. In the study by Purdy *et al.* (2002c), there was one animal that showed an increase in haptoglobin. In the studies examined, none of the researched examined changes in cortisol concentrations. Cortisol is frequently used as a measure of stress in animals.

4.3.2.4 The effects of endotoxin

All gram-negative bacteria produce endotoxin. Endotoxin (ET) is a relatively heat stable, biologically active material the profoundly affects both humoral and cell mediated immunity (Burrell 1990). Gram-negative bacterial are sensitive to heat and desiccation and are not cultured from feedlot dust. Typically, feedlot dust contains large numbers of gram--positive bacteria as well as fungi.

A study was conducted by Purdy *et al.* (2002c) to determine which component of feedlot dust was most biologically active. To do this, feedlot dust was autoclaved. This process would preserve most of the endotoxin and totally inactivate all microbes. A second treatment was to oven-heat feedlot dust. This treatment would inactivate all endotoxin and microbes. The untreated feedlot dust would contain intact endotoxin and viable microbes. The untreated feedlot dust contained 26.9 µg ET/g of dust. This untreated dust contained 0.539 g/ (m^3min) of dust and 14.5 µg ET/ (m^3min). This caused a significant rise in rectal temperature and total WBC counts in weanling goats when administered as an aerosol into an enclosed tent. The autoclaved dust contained 13.3 µg ET/g of dust.

The autoclaved dust in the tent contained 0.369 g/ (m^3min) of dust and 4.904 µg ET/ (m^3min). The autoclaved dust contained 2.95 times less endotoxin that the untreated feedlot dust aerosol. Both the untreated dust and the autoclaved dust induced high rectal temperatures at 4, 8 and 12 hours post treatment. Total WBC counts were increased over a 12-24 hour period. Neutrophils were increased at 8 and 12 hours. Absolute lymphocytes showed a trending decrease in 4-8 hours.

The dry-heat almost totally destroyed the endotoxin content (0.173 µg ET/g dust). The dry-heated dust aerosol in the tent contained 0.347 g/ (m^3min) of dust and 0.0015 µg ET/ (m^3min). The goats treated with the dry-heated dust aerosol did not respond with increased rectal temperatures, increased total WBC, increased neutrophils and decreased lymphocytes compared to the control goats.

This study showed that the most significant biologically active component of feedlot dust was the endotoxin fraction and not the culturable microbes or the ultrafine dust which could carry other toxins and radicals.

4.3.2.5 The effect of dust on pulmonary bacterial populations

A study by Purdy *et al.* (2003) tested the hypothesis that animals that inhale large quantities of feedlot dust are more predisposed to pulmonary bacterial proliferation. Using goats, the treated animals were dusted in a semi-airtight tent and received a transthoracic challenge of live *Mannheimia haemolyticia* ($4x10^6$ CFU) or live *Pasteurella multocida* ($1x10^6$CFU). The control animals received the bacteria and were not dusted. The dusted animals showed a significant increase in rectal temperatures. The dusted animals also showed a dramatic leucocytosis with neutrophilia after the first dust treatment. This effect was not sustainable. The dusted animals showed a temporary decrease in appetite for 4 days compared with the controls. On repeated dust exposures, rectal temperature tolerance occurs. This also occurred with total WBC counts (Purdy *et al.* 2002b). On post mortem *M.Haemolytica* and *P. multocid*a were successfully cultured from the respective treatment goats. The study found that the ability of goats to clear either large concentrations of *M. Haemolytica* or *P. Multocida* injected into the right lung was not affected. Dusted goats cleared the organisms as well as the control non-dusted goats. This study shows that even though alveolar macrophages ingest dust particles, this does not appear to affect their ability to ingest and kill potential bacterial pathogens and that inhalation of large quantities of endotoxin-laden feedlot dust did not predispose animals to pulmonary bacterial proliferation.

4.3.2.6 Pathological findings in dust challenged animals

Two studies (Purdy *et al.* 2002a; Purdy *et al.* 2002b) examined the lungs of dusted sheep and goats in separate experiments both grossly and histopathologically. The findings were similar for both studies. No grossly observable differences were detected in the respiratory tracts of the control and treated animals. There were histological changes in all treated animals whether or not they had received tilmicosin phosphate. There was a generalised mild alveolar septal thickening and hypercellularility as a result of infiltration with macrophages, lymphocytes and neutrophils. The bronchioles and terminal airways had exudate consisting of neutrophils and macrophages filled with foreign particulate matter and siliceous material. There was an increase in bronchial associated lymphoid tissue in one study whereas the other study had lymph nodes filled with black carbon that was used as a dust marker in the study.

The diagnosis was a mild acute exudative broncho-interstital pneumonia (Purdy *et al.* 2002a). The second study described the lesions as a mild sub-acute interstitial pneumonia. (Purdy *et al.* 2002b). In both studies the control animals did not have any histological changes.

4.3.2.7 Livestock exposure guidelines

The current recommendations for continuous exposure of livestock to dust specify a “safe” concentration for non-specific dust of 3.4 and 1.7 mg/m^3 for inhalable and respirable concentrations respectively (Wathes 1994) as cited in Takai *et al.* (1998) and Wathes (1998). These guidelines are significantly lower than human exposure guidelines of 10 mg/m^3 developed for nuisance dust by Safe Work Australia (2011). Differences in exposure guidelines are due to animal exposure times being measured over 24 hours, whilst human exposure is only measured over 8 hours to coincide with a typical working day. If livestock guidelines would be adjusted over 8 hours, these would read 10.2 and 5.1 mg/m^3 for inhalable and respirable particulates respectively, showing livestock have similar sensitivities to dust as humans.

4.3.3 Impacts on employees and contractors

Manure-related dust in feedlots may have potential to cause health problems in cattle and humans (Seifert *et al.* 2003). The health problems can be due to:

1. The inhalation of fine particles
2. The inhalation of toxins

4.3.3.1 Particle size categorisation

Dust constituents may differ but, in the absence of detailed information on dust composition, particle size will have the greatest impact on human and animal health.

The two human health categories of dust (based on particle size) are termed inhalable and respirable (Safe Work Australia 2012). Inhalable dust comprises a broader range of particle sizes and includes any dust that can enter the nose and mouth during normal breathing processes (Safe Work Australia 2012). Respirable dust comprises smaller dust particles that can pass from the nose and mouth into the lower bronchioles and alveoli of the lungs where oxygen and carbon dioxide exchange occurs (Safe Work Australia 2012).

Table 3 illustrates the relative proportion of inhalable and respirable dust based on particle size.

Earlier classifications of PM (WHO 1999) included thoracic particulates (Table 3), which is a category between inhalable and respirable dust and includes dust that is passed from the nasal and mouth passages into the airways of the lungs, but not as far as the bronchioles where oxygen is transferred to the blood. The earlier values of inhalable and respirable fractions were very similar to those included in more recent guidelines, i.e. Safe Work Australia (2012), so only the additional thoracic fractions from this earlier data have been included in Table 3.

Table 3 – Inhalability and respirability of dust particle sizes

Particle size [A] (µm)	Inhalable [B] (%)	Thoracic [C,D] (%)	Respirable [B,C] (%)
0	100	100	100
2	94	94	91
3	92	91	74
4	89	89	50
5	87	85	30
6	85	80	16
7	83	74	8
8	81	67	4
10	77	50	1
12	74	35	0
14	72	23	0
16	69	15	0
18	67	9	0
20	65	5	0
30	58	0	0
60	51	0	0
100	50	0	0

[A] Equivalent aerodynamic diameter
[B] Source: Australian Standards 3640 and 2985 as cited in Safe Work Australia (2012), pp. 19-20, % by equivalent aerodynamic diameter (µm)
[C] proportion of inhalable dust that is respirable; % by equivalent aerodynamic diameter (µm)
[D] Source:ACGIH (1999); % by equivalent aerodynamic diameter (µm)

Based on the penetration potential of dust particles (Table 3), most environmental and health researchers use particle size categorisations based on the upper aerodynamic diameter cut-off values of 2.5 µm ($PM_{2.5}$) and 10 µm (PM_{10}) (WHO 1999). Respirable particles, therefore, are those in either $PM_{2.5}$ or PM_{10} range, and inhalable PM include those within the broader TSP category. Larger particles > 50 µm have poor inhalability and rarely remain airborne for long (WHO 1999).

Workplace health and safety guidelines have been developed to mitigate potential health risks. Generically, the main health effects of airborne particles discussed in the Safe Work Australia *Guidance on the Interpretation of Workplace Exposure Standards for Airborne Contaminants* (Safe Work Australia 2012) are:

- systemic toxic effects caused by the absorption of the toxic material into the blood, for example, lead, manganese, cadmium and zinc
- allergic and hypersensitivity reactions caused by the inhalation of dusts from materials such as flour, grains, some woods and some organic and inorganic chemicals
- bacterial and fungal infections associated with the inhalation of dusts containing viable organisms and/or spores
- fibrogenic reactions in the gas exchange regions of the lung due to the presence of materials such as asbestos and quartz
- carcinogenic response due to the presence of, for example, chromates and asbestos; and
- irritation of the mucous membranes of the nose and throat caused by acid, alkali or other irritating particulates, especially mists.

Other ways that dust may impact on the long term safety of workers, however, include:

- antibiotics and antibiotic resistant bacteria (McEachran 2015), although this is largely unverified, see Section 4.2.5.3.
- reduced visibility (Safe Work Australia 2012)
- deposition of dust in ears and eyes (Safe Work Australia 2012)
- deposition of dust on surfaces or equipment (Safe Work Australia 2012); and
- increased respiratory tract infections and epithelial cell protein kinase C (PKC). Stimulation of PKC from feedlot dust has been shown to activate the lung inflammatory mediators interleukin 6 (IL-6) and interleukin 8 (IL-8) (Wyatt *et al.* 2014).

The Workplace Exposure Standards for Airborne Contaminants (Safe Work Australia 2011) identify maximum exposure limits for a number of chemicals and dust constituents. A list of exposure limits for particulate materials which may be emitted from cattle feedlots is given in Table 4.

Table 4 – Exposure limits to sundry agricultural dusts

Dust source	Exposure limit
Grain dust	Time weighted average (TWA) 4 mg/m^3
Vegetable oil mists (except castor oil, cashew nut or similar irritant oils)	TWA 10 mg/m^3, which may be relevant to oil spray applications
Wood dust	TWA 5 mg/m^3, which may be relevant to dust mulch application

Feedlot dust generally cannot be placed into any of the categories prescribed by Safe Work Australia (2011). Exposure standards for ‘dust not otherwise classified’ (nuisance dust) is set at an 8 hour TWA of 10 mg/m^3, which is calculated over a five-day working week (Safe Work Australia 2012). Nuisance dust is required to have low inherent toxicity and to be free from toxic impurities. Due to the variable nature of feedlot dust emissions, a large proportion of emissions may not be classified as nuisance dust, particularly for fine particulate materials (<10 µm). Standards prescribed by Safe Work Australia (2012) do not take into account different susceptibilities to nuisance dust and some individuals may experience adverse health effects at levels below exposure standards (Safe Work Australia 2011).

The United States Environmental Protection Agency (US EPA 2016b) specifies $PM_{2.5}$ and PM_{10} exposure standards (Table 5). Exposure standards based on PM size class are particularly relevant for the lot feeding industry in Australia where a large proportion of feedlot dust may be categorised as less than <10 µm (Galvin *et al.* 2005). Interestingly, exposure standards prescribed by Safe Work Australia (2012) appear more stringent than the US EPA (2016b) which takes into account sensitive individuals such as asthmatics, children and the elderly.

Human health impact studies of dust generated by animal feeding operations have also included the recent systematic review (a tightly defined protocol for meta-analysis of literature) by O’Connor *et al.* (2010), an update of which will be published sometime later this year (Auvermann 2016). Interestingly, O’Connor’s original report (O’Connor *et al.* 2010), found that there was little compelling evidence for a consistent strong association between clinical measures of human disease and proximity to animal feeding operations (AFOs).

Table 5 – US EPA national ambient air quality standards for $PM_{2.5}$ and PM_{10}

Pollutant	Primary/Secondary	Averaging Time	Level	Notes
$PM_{2.5}$	primary*	1 year	12.0 µg/m^3	annual mean, averaged over 3 years
$PM_{2.5}$	secondary#	1 year	15.0 µg/m^3	annual mean, averaged over 3 years
$PM_{2.5}$	primary and secondary	24 hours	35 µg/m^3	98th percentile, averaged over 3 years
PM_{10}	primary and secondary	24 hours	150 µg/m^3	Not to be exceeded more than once per year on average over 3 years

Source: US EPA (2016b)
*Primary Standards provide public health protection, including for sensitive populations, such as asthmatics, children, and the elderly
#Secondary Standards provide public welfare protection against decreased visibility, damage to animals, crops, vegetation and buildings.

4.3.3.2 Q-Fever

Q-fever is a significant infectious disease which spreads from animals to humans through aerosols, contaminated dust, animal products and manures (Kubik 2006). Q-fever infection is caused by C*oxiella burnetii* which is an obligate intracellular bacterial pathogen found in sheep, goats and cattle (Casey *et al.* 2015). *C. burnetii* is most abundant in foetal/placental fluids and tissues, where concentrations may be as high as 10^9 organisms per gram of material (Lugton 2016).

Workers handling foetal/placental fluids are at greatest risk of infection which is mostly acquired via the respiratory route (i.e. infectious fluids suspended as fine aerosols). Despite a reduced prevalence of *C. burnetii* in feedlot dust and animal manures, Q-fever is highly infectious (AMPC 2016a) and infections may be acquired from these materials.

C. *burnetii* survives well in air, soil and water, and may survive for over a year in dust particles (Lugton 2016). High survivability of C. *burnetii* pathogens presents a long term Q-fever infection risk, which may persist even after livestock facilities have ceased operations. Q-fever infections have the potential to detrimentally affect the health and safety of feedlot workers, visitors, and the surrounding community. Although animal manures are generally not considered a major source for Q-fever infections, goat manure has been correlated with an increased incidence of Q-fever infections in the Netherlands (Smit *et al.* 2012; Hermans *et al.* 2014), as cited in Casey *et al.* (2015).

Signs of infection include a rapid onset of flu like symptoms including fever, sweating, nausea, vomiting and diarrhoea which may last for 1 to 3 weeks if left untreated (AMPC 2016b). In very rare cases, around one in 50 people may require hospitalisation due to complications associated with hepatitis, pneumonia and meningoencephalitis (Lugton 2016). A low number of deaths have also been attributed to Q-fever, although these deaths are mostly found amongst the elderly or debilitated (Lugton 2016) who may be suffering from other health complications. On-going symptoms arising from Q-fever may be diagnosed as Post Q-Fever Fatigue Syndrome. Symptoms may include extreme tiredness, muscle pains, fever and depression, and these symptoms may persist for month or years (AMPC 2016b).

4.3.3.1 Organic Dust Toxic Syndrome (ODTS)

In humans, Organic Dust Toxic Syndrome (ODTS) is a clinically recognised self-limiting syndrome most commonly reported by farmers and livestock confinement workers following exposure to mouldy grain, silage, hay and wood chips. Symptoms have also been reported by people tending cattle (Pratt and May 1984; Seifert *et al.* 2003). The syndrome usually begins within hours of exposure to high concentrations of organic dust and is categorised as an inhalation fever with signs of fever with chills, malaise, myalgia, headache, dyspnoea, chest tightness, dry cough and nausea. (Pratt and May 1984; Hurst and Dosman 1990). ODTS can be differentiated from other similar pulmonary exposure conditions, namely hypersensitivity pneumonitis (HP) and Oxides of nitrogen (NOx) (Seifert *et al.* 2003). Fungal spores, mycotoxins and endotoxins are implicated, though the exact mechanism of toxicity is unknown. The mechanism of toxicity is considered to be non-immunogenic (Wilson *et al.* 2002).

4.3.3.2 Other impacts of dust on humans

Wyatt *et al.* (2007) showed that in humans, exposure to feedlot dust extract stimulated bronchial epithelial interleukin (IL) -8 and IL-6 release via a protein kinase Cε (PKCε) – dependant pathway. Gimble (1997) suggests that antigenic receptor stimulation could result in macrophage recruitment and their secretion of proinflammatory cytokines, such as tumour necrosis factorα, IL-1 and IL-6 (Adler *et al.* 1994). Gimble (1997) concluded that the antigenic stimulation of the respiratory tract by dust particles, endotoxin, other exogenous substances or pathogens has the potential of inducing two general responses: proinflammatory response and immune response.

4.3.4 Impacts on the community

Dust emissions from cattle feedlot operations are generally regarded as an amenity issue (i.e. nuisance related) rather than a workplace health and safety issue (as it applies to feedlot staff and contractors). This is because dust experienced by the community is usually relatively minor and does not have the same dust concentration, frequency and duration as that experienced by feedlot staff. However, if specific circumstances occurred where the community experienced feedlot dust at a significantly higher concentration, frequency and duration to that experienced by feedlot staff, the impacts would be similar to those described in Section 4.3.3.

Natural attenuation processes result in feedlot dust deposition in the natural environment, including on vegetation and soils. Todd *et al.* (2004) found pastures were severely degraded 500 m downwind from a 25,000 head Texas feedlot, although environmental impacts appeared to be localised. Effects of air pollution and PM on vegetation can include necrosis, chlorosis (bleaching or colour change), or alteration in growth (Todd *et al.* 2004). Similar issues have not been reported in Australia.

In the USA, some feedlots have been built very close to public roads and highways. In some circumstances, the dust plumes emitted from the feedlots have caused significant traffic hazards on those public roads. Road safety issues due to feedlot dust have not been reported in Australia.

4.4 Manure-related dust hazard control

4.4.1 Elimination

At a feedlot, manure-related dust hazard needs two elements for it to occur. Either of these two elements could be addressed to reduce dust hazard. They are:

1. A source of fine, dry manure with small particles sizes, and
2. A means for the dust to become airborne being either livestock, traffic or wind.

Usually, very little can be done to prevent fine dry manure from becoming airborne. It is not possible to stop livestock becoming active in the late afternoon. Livestock must be moved in cattle lanes and held in holding yards. Manure must be removed from pens and processed. Wind cannot be controlled. Hence, the elimination of dust must focus on the creation of fine, dry material. The elimination of manure-related dust could include:

1. Elimination of manure, or
2. Elimination of dry manure

4.4.1.1 Manure removal

Uncompacted or loose manure can lead to increased dust emissions (Lorimor 2003; Rahman *et al.* 2008), with deep uncompacted dry manure generating the most dust (Auvermann *et al.* 2000). The removal of loose manure can greatly reduce dust generation and odorous gases (Auvermann 2001; Lorimor 2003; Rahman *et al.* 2008). More frequent, or continuous, manure removal has been trialled in Texas with promising results and was shown to have little to no effect on cattle performance or stress (Auvermann 2001). In fact, most Australian feedlot nutritionists believe that there are improvements in ADG due to more frequent manure removal. Frequent manure removal is a particularly important strategy where water limitations restrict the use of sprinklers (Bush *et al.* 2014). Traditionally, manure removal in the US has not tended to be particularly frequent and pens are typically cleaned only once per year, although some may be cleaned twice per year under the United States Department of Agriculture Natural Resources Conservation Service (USDA-NRCS) program (Casey 2016).

An interface layer of dark, moist compacted manure some 25 – 50 mm thick has been documented in feedlot pens (Auvermann 2001; Lorimor 2003; Rahman *et al.* 2008; Auvermann and Casey 2011). Photograph 6 shows the interface layer in a feedlot pen. The preservation of this interface layer during cleaning activities is desirable as it helps to reduce dust generation from underlying soil materials and protects cattle hooves from stony ground. The compacted nature of the interface layer leads to low water infiltration which protects underlying soil and groundwater resources from the accumulation of excess nutrients (Sweeten 1998). Excessive cleaning of pens results in the removal of the compacted manure interface layer exposing the underlying clay and gravel which can increase dust generation and can be damaging to cattle hoofs (Lorimor 2003). Photograph 7 shows pen cleaning is possible while retaining a good interface layer.

A number of pen cleaning techniques such as excavators and front-end loaders are used but only box scrapers are discussed here. This is because it is more difficult for operators to accurately control front-end loaders using a pushed scraper blade than box scrapers which use a pulled blade (Auvermann 2001; Lorimor 2003).

The use of box scrapers is the current best practice for manure removal (Auvermann 2001; Lorimor 2003). Box scrapers using a pulled blade which is able to carefully remove surface manures whilst leaving the interface layer intact (Auvermann 2001). This technology has been trialled in a few large Texas feedlots (capacity >35,000) with excellent results and little to no depression in animal performance or increased cattle stress (Lorimor 2003).

The experience of Australian lot feeders is that manure removal is most efficient when the pen manure is at about 30-40% moisture content. Photograph 8 shows a box scraper mounding pen manure under optimal moisture conditions. Several of the feedlot managers interviewed believed that more frequent pen cleaning has the biggest impact on dust. Some clean at a frequency of every 40 days (or less), regardless of the apparent depth of manure in the pen or manure moisture content. This is an insurance policy against unforeseen very dry or very wet conditions.

In general, pen cleaning under very dry dusty conditions does not occur. However, some lot feeders have found that mounding dry pen manure in a corner of the pen can reduce dust generation as it reduces the pen area where dusty manure exists. It is difficult to remove this very dry manure from the pens and removal of that dry material would create considerable dust in itself. Photograph 9 and Photograph 10 show mounding of dusty manure to minimise daily dust generation by livestock. One lot feeder commented that they do this once every 10 days during peak dust periods.

However, other lot feeders believe that once the mound of dry dusty material has been formed, cattle will play with the mound and spread the dusty material back across the pen. No research information was found to determine the effectiveness of in-pen dry manure mounding.

Photograph 6 – Manure interface layer in feedlot pen

Photograph 7 – Pen cleaning with retention of the interface layer

Photograph 8 – Pen cleaning under moist conditions

Photograph 9 – Pen cleaning under dry conditions – mounding dusty material

Photograph 10 – Mounding dusty material in pen corner

4.4.1.2 Pen surface moisture management

One method to eliminate manure-related dust from pens is to make the manure moist. There are two ways in which pen moisture content can be managed.

1. Management of stocking density
2. Application of additional water

4.4.1.3 Moisture control through management of stocking density

Stocking density of cattle has a significant effect on the moisture content of the pen surface through the addition of moisture in manure. Increased stocking density results in increased added moisture (Fig. 3). Optimising stocking densities can play an important role in reducing dust emissions from cattle feedlot operations (Auvermann *et al.* 2000; Wanjura *et al.* 2004; Rahman *et al.* 2008; Bush *et al.* 2014).

Increased stocking densities may provide dust management strategy through increased manure generation (Bush *et al.* 2014). Early studies by Auvermann *et al.* (2000) yielded inconclusive results, though recent studies by Bush *et al.* (2014) showed an apparent **86% reduction** in dust emissions following a doubling of the stocking density from 14 m^2 hd^{-1} (150 ft^2 hd^{-1}) to 7 m^2 hd^{-1} (75 ft^2 hd^{-1}). Rahman *et al.* (2008) concluded that increased stocking densities in a Texas feedlot (USA) may also reduce dust emissions through reduced animal activity, although additional mechanisms for reduced dust emissions were not examined. Other mechanisms for reduced dust emissions following increased stocking densities may include increased shading of the pen surface and increased intensity of hoof action resulting in increased bulk density and greater manure stability (Bush *et al.* 2014). These mechanisms should be considered in combination to understand the contributing factors in reducing dust emissions.

Sweeten (1998) concludes that the choice of stocking densities is highly influenced by climatic conditions. Arid climates (i.e. below 250 mm annual rainfall) lead to rapid depletions in soil moisture which leads to increased dust generation. Under these conditions, stocking densities can be maintained quite high, i.e. 9.3 m^2 hd^{-1} (Sweeten 1998). Moderate rainfall zones (i.e. 500 mm annual rainfall) result in reduced stocking densities (i.e. 14 to 21 m^2 hd^{-1}) to accommodate for increased rainfall inputs (Sweeten 1998). Humid high rainfall environments (i.e. 750 mm annual rainfall) are not ideal for feedlot operations as water management can be problematic due to odour. Due to excess rainfall, stocking densities are kept low (i.e. 28 to 37 m^2 hd^{-1}) to reduce further manure inputs (Sweeten 1998; Rahman *et al.* 2008).

However, management difficulties arise when there is a marked change in climate throughout the year (Section 4.1.1). In areas of winter-dominant rainfall, the pens are wet in winter (and a low stocking density would be appropriate) and dry in summer (and a high stocking density would be appropriate). Hence, changing stocking density throughout the year is desirable.

There are practical issues that need to be addressed when considering increasing pen stocking density. Fig. 11 shows a typical feedlot pen. There is a feed bunk that runs along the full length of the top section of the pen and there are water troughs somewhere in the lower section of the pen. There also may be a band of shade in the centre or lower end of the pen. Fig. 12 shows the design parameters for a pen. Three design parameters determine the size of a pen:

1. Stocking density (m^2 per head)
2. Feed bunk length (mm per head)
3. Pen capacity (head)

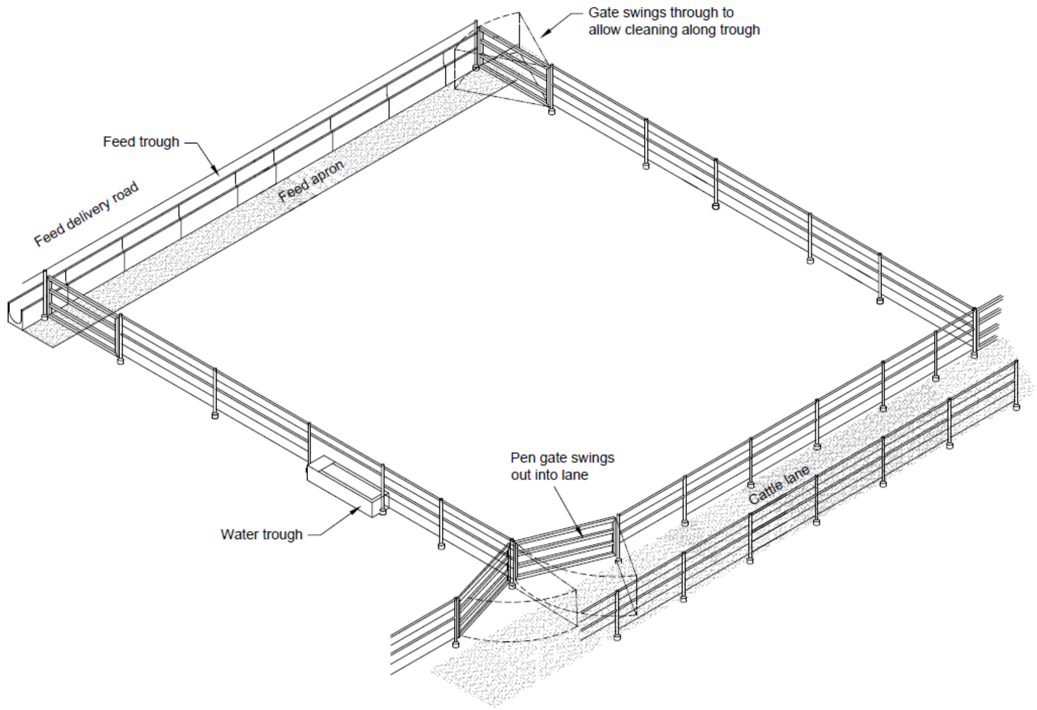


Fig. 11 – Typical feedlot pen layout

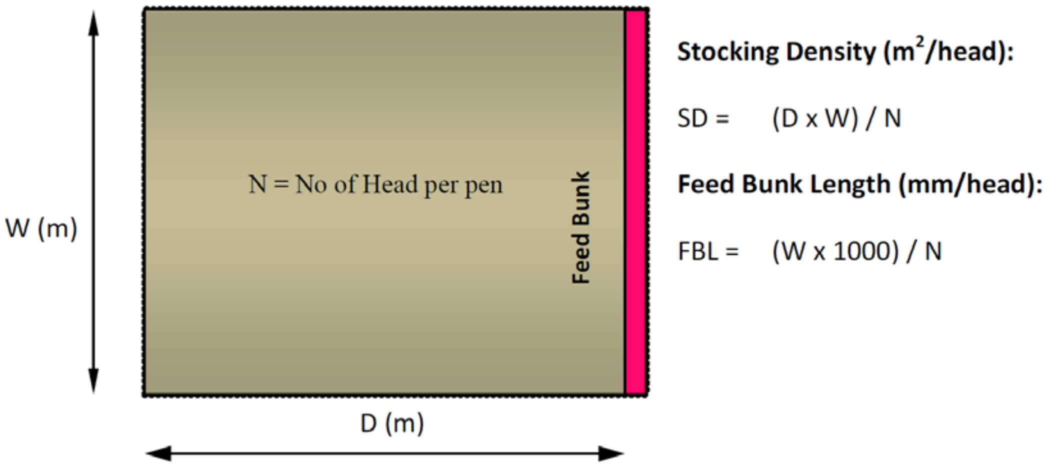


Fig. 12 – Feedlot pen design parameters

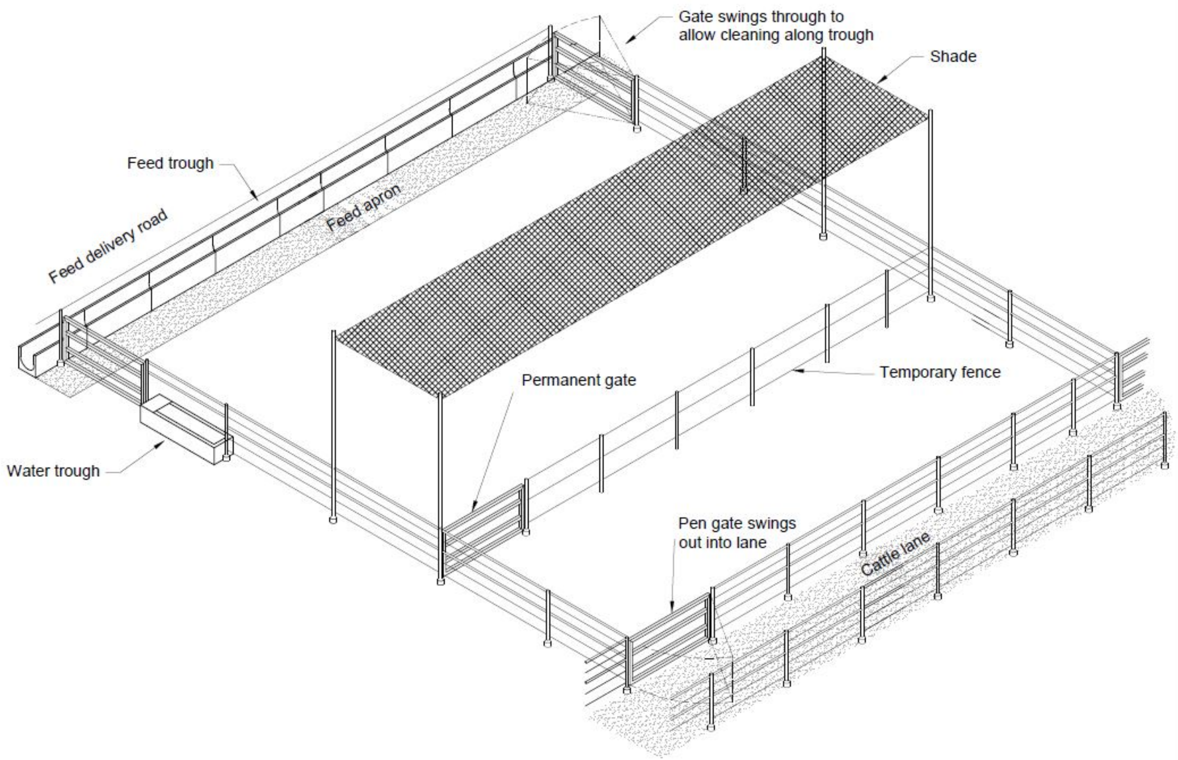


Fig. 13 – Modified Feedlot Pen Layout

Increasing cattle numbers per pen

A typical design for an Australian feedlot would be a stocking density of 15 m^2/head, a bunk length of 300 mm/head and a pen capacity of 200 head. This would lead to a bunk length (W) of 60 m and a pen depth (D) of 50 m. For 450 kg cattle, this would result in about 490 mm of moisture added per year by cattle. In most climates, evaporation could easily remove this moisture and the pen would not be sufficiently wet to cause odour problems. If the stocking density in this pen is increased to 9 m^2/head, the annual moisture added would be increased to about 820 mm per year. This reduces dust creation by keeping the pen surface moist. This would increase pen capacity to about 330 head but would reduce bunk length to only 180 mm/head.

There may be commercial (consignment size) reasons for not changing the number of cattle in a pen. However, the main concern is access to feed. The higher stocking density would require more frequent feeding (e.g. twice per day to three times per day). However, most nutritionists now believe that increased bunk space per head leads to increased cattle performance. It is possible that the increase in stocking density described above would lead to reduced cattle performance.

Another issue with increasing stocking density is the possibility of heat stress events. Some lot feeders are concerned that, if the pens were packed tightly, an unexpected rainfall event could lead to high humidity on pens and a potential heat stress event.

Reducing available pen area

There is one method used at some feedlots in the USA and attempted at some Australian feedlots. The aim is to increase stocking density for dust control, without changing bunk length per head. The method is to string an electric fence (or similar), parallel to the feed bunk, across the bottom third of the pen (see Fig. 13 and Photograph 11). However, this can only work if the water troughs (and shade, if in place) is in the top section of the pen (see modified feedlot pen layout - Fig. 13), rather than the typical trough location shown in Fig. 11. This approach was one the treatments used by Bush *et al.* (2013). In this study, Bush *et al.* (2013) doubled the stocking density from 14 m^2 hd^{-1} (150 ft^2 hd^{-1}) to 7 m^2 hd^{-1} (75 ft^2 hd^{-1}) by halving the pen area using an electric fence. This proved to be a successful strategy as Bush *et al.* (2013) found that PM_{10} emission factors decreased from 50 kg dust generated per 1,000 hd per day (50.73 kg/1,000 hd-day) to 7.04 kg/1,000 hd-day, representing a **86% reduction** in dust generation. The fenced off portion of the pen is likely to still contain a source of fine dry material, although the exclusion of cattle from this area reduces ground disturbance and limits the potential for this material to become airborne. The second treatment involved doubling the stocking densities by doubling the number of cattle and maintaining the same pen area. This strategy further reduced PM_{10} emission factors to 4.55 kg/1,000 hd-day. The further reduction in emission factors may be due to increased dust generation from the fenced off areas in Bush’s first experiment.

There are practical issues to be resolved before this approach can be used. Experience has shown that new cattle, as a mob, can “rush” an electric fence and knock it over. A combination of stronger fencing, more visible fencing and livestock training would be required to make this dust elimination solution viable.

Photograph 11 – Variable stocking densities

(Broken Bow Feedlot, Neb, USA)

Increasing manure excretion rates

One approach used by an Australian lot feeder to increase moisture added to the pen surface is to cause the cattle to excrete more urine. This is done by adding salt to the ration. Anecdotally, this has shown good results. However, the manure excretion rates reported in the literature are not sufficiently accurate to quantify the amount of extra moisture excretion (via increased drinking water intake) due to the addition of salt to the ration.

Regulatory issues

Manipulating stocking densities can be an effective low cost strategy for reducing dust emissions in cattle feedlots. However, it needs to be noted that the minimum stocking density allowed in Australia, as per animal welfare standards, is 9 m^2 per SCU (National guidelines (AAWS 2013). Furthermore, most feedlots believe that rigid licensing conditions prevent them from changing stocking density throughout the year.

4.4.1.4 Moisture control through sprinkling systems

The other method that is used to add moisture to the pen surface is sprinklers as used in the irrigation industry. Sprinkling systems are employed to control dust emissions from cattle feedlot operations (WSDE 1995; Auvermann *et al.* 2003; Amosson *et al.* 2006; Bush *et al.* 2014) and have the added benefit of reducing heat load stress in cattle (though shading can be more effective) (Marcillac-Embertson *et al.* 2009). Dust emissions are reduced when moisture in the pen area is kept to within 25 and 40% (Davis *et al.* 1997; Auvermann *et al.* 2000; Lorimor 2003) and this often necessitates the need for additional water (WSDE 1995). Water needs to be applied with care since the moisture content of a typical feedlot varies considerably, with moisture content tending to be greatest on the pen surface near feed bunks and water troughs (Rahman *et al.* 2008).

Sprinkler systems should be designed to provide maximum practical coverage of the pen area (WSDE 1995) which is aided by having a regular pen design. Operators have the option of having a high-pressure sprinkler system with fewer sprinkler heads, or a low-pressure system with a greater number of sprinkler heads (WSDE 1995). The preferred sprinkler system design will depend on pen layout characteristics (WSDE 1995) and the system should be designed so that the sprinkler aprons overlap 50% of the diameter of the throw (Lorimor 2003). Sprinkler systems are not routinely used for Australian feedlots due to high setup costs and reduced water availability, although sprinklers may be used for limited areas where dust emissions may be increased, or where cattle have a greater probability of developing respiratory disorders. For example, some feedlots choose to only install sprinklers in areas used for incoming cattle since these cattle tend to be more immunologically naïve and have an increased risk of developing BRD symptoms (Sanderson *et al.* 2008; Hay *et al.* 2014).

Sprinkler systems are effective in reducing mean PM_{10} concentrations (Lorimor 2003; Marcillac-Embertson *et al.* 2009; Bonifacio *et al.* 2011) and can also cause a lowering in NH_3 emissions (Marcillac-Embertson *et al.* 2009). These effects are only apparent in the short-term, with Bonifacio *et al.* (2011) noting that the effects of a sprinkler system in reducing PM_{10} concentrations in a feedlot in Kansas lasted for only one day or less. This is not surprising since water molecules are held together by hydrogen bonds which also bind to soil particles and reduce dust generation. When water is lost through evaporation, these effects are reduced and dust generation is increased.

Sprinkler systems work well for low wind speed scenarios where they can apply a uniform water coverage. High winds reduce their effectiveness (WSDE 1995; Bush *et al.* 2014). Soil particles and manure in cattle feedlot pens have a high organic matter content and this provides a cohesive surface crust which has good moisture retention and erosion resistance properties. A soil's ability to become cohesive when wetted depends on the surface charges of soil particles as well as surface tension effects (Turner *et al.* 1987), and not all soils possess these favourable wetting characteristics. When using sprinkler systems, water is only taken up by the soil/manure when the threshold entry pressure of the pores has been overcome. Unfortunately, like other organic compounds, feedlot manure tends to be hydrophobic, which reduces wettability and increases the threshold entry pressure required to take up water (Wang *et al.* 2000).

To maximise dust mitigation efforts, moisture content in the pen area should be maintained at depth since cattle hoof action easily disturbs surface manures leaving underlying manure exposed to dust generation (Auvermann *et al.* 2000). This requires a lot of water (especially due to the hydrophobic nature of organic materials) although feedlot holding pond water can be recycled for this purpose (Amosson *et al.* 2006). Research from the US has shown that falling groundwater levels has meant that some feedlots have insufficient water to operate their sprinkler systems (Casey 2016). Water may also be sourced from holding ponds, although this is not commonplace due to public perception concerns, and water may also be limiting from these structures during summer (Casey 2016). Frequent pen cleaning may also be a successful strategy in reducing sprinkler water requirements by reducing the depth of manure, thereby reducing manure wetting requirements (Auvermann *et al.* 2000). Research by Turner *et al.* (1987) shows that sprinkler systems can reduce dust emissions by 25 to 90% in feedlot settings. Differences in effectiveness are likely related to surface wetting requirements and the volume of water applied.

Solid-set sprinklers

Solid set sprinklers (Photograph 12) are increasingly desirable for new feedlot developments in dry-prone areas of the USA (Auvermann *et al.* 2003) because of their automation and ability to cover the entire feedlot area at the same time (WSDE 1995; Auvermann et al. 2003). Solid-set sprinkler system nozzles are capable of shooting water across feedlot pens to help settle dust.

The high costs of installing solid-set sprinklers (which are greater when retrofitting to existing operations) (Auvermann *et al.* 2003) can be prohibitive to small operators, although costs are offset by automation and reduced labour requirements (Queensland Government 2003; Amosson *et al.* 2006).

The use of solid-set sprinklers in cattle handling yards and lanes is cost-effective and are increasingly being installed at Australian feedlots (Photograph 13 and Photograph 13).

Mobile sprinklers

Mobile sprinklers require trained operators to effectively cover the entire pen area and to deliver the correct quantities of water necessary for effective dust mitigation (WSDE 1995). Care also needs to be taken to maintain moisture at depth to reduce dust generation from underlying materials disturbed by cattle trampling. The time taken for mobile sprinklers to effectively cover the feedlot area may see increased dust generation before the entire site has been covered (WSDE 1995). Increased labour requirements may also result in high operating costs, especially for high wage countries such as Australia and the USA. Mobile sprinklers are typically less efficient than solid spread sprinklers (see above), although they may be appropriate for existing or smaller feedlot operations due to reduced capital cost.

Water availability constraints

Very few feedlots in Australia have excess clean water availability. Water supplies are usually limited via regulatory licensing arrangements. Large quantities of water are required to successfully and consistently eliminate dust from pens. Feedback from most of the Australian lot feeders contacted in the study suggested that water availability is the main constraint to this approach.

4.4.1.5 Elimination of Q-fever

Elimination of Q-fever is not possible as C. *burnetii* has a high prevalence in sheep, goats and cattle nationwide.

4.4.2 Substitution

4.4.2.1 Fully-covered feedlot housing

An example of a substitution solution to manure-related dust generation could be substituting open feedlot pens with clay or gravel pen foundations with fully-covered sheds (i.e. intensive livestock housing). This is the approach used in pigs and poultry.

The poultry industry has researched PM concentrations and dispersal characteristics (Li *et al.* 2012), and the relationship between dust emissions with feed (Robertson *et al.* 2002), odour, greenhouse gas (Carey *et al.* 2004a; Carey *et al.* 2004b; Lacey *et al.* 2004) and litter/manure moisture (Carey *et al.* 2004b). Respirable particulate concentrations in broiler buildings were found to be significantly influenced by the cleaning regime, bird density, ventilation and humidity (Banhazia *et al.* 2008). Specific research and guidance exist for the poultry industry on the use of sprinkling systems (Brisbane City Council 2000; Carey *et al.* 2004b); sealed shed floors (Brisbane City Council 2000); adequate ventilation (Banhazia *et al.* 2008), vehicle reduction (Brisbane City Council 2000) and the siting and management of litter/manure stockpiles (Brisbane City Council 2000; Mukhtar *et al.* 2004).

Dust abatement technologies used by the poultry industry include air scrubbers (Melse and Timmerman 2009), filters (Mostafa and Buescher 2011), biofilters, windbreaks, oxidants and misting screens (Ullman *et al.* 2004a). Biofilters are particularly effective for the control of PM emissions from poultry sheds (see Table 6), and comparable efficiencies have also been observed for dry filters with up to 72% reductions in PM concentrations being recorded (Mostafa and Buescher 2011).

Low-cost techniques including adequate ventilation are particularly effective for reducing airborne dust concentrations in indoor intensive livestock buildings, although pollution to the surrounding environment may be increased (Dando *et al.* 2000). Environmental assessments should be based on sensitive receptor areas, and in the absence of significant environmental constraints, ventilation may be seen as an important strategy for effective particulate control. The US EPA (2001) '*Emissions from Animal Feeding Operations*' report states that confinement facilities for dairy and beef cattle are typically naturally-ventilated, and this is an effective dust mitigation control. Airborne dust is also rapidly diminished through sedimentation, with natural gravitational settling shown to remove up to 74% of particulate materials (by mass) in a piggery in the absence of dust control techniques (Carpenter and Fryer 1990).

Table 6 – Performance Data for the Control of Particulate Emissions from the Poultry Industry

Source	Technology	Target Emission Percent Reduction
Animal Housing	Barriers	60*
	Biofilters	68*
	Landscaping	59*
	Scrubbers	52*
	UV Light	16*

Source: Adapted from Maurer *et al.* (2016)
Target Emission % Reduction Calculated over All Scales

Research associated with piggery dust has analysed:

- effectiveness of electrostatically charged water spray (Almuhanna 2007) and disinfectant fogging (Costa 2014) for dust control
- impacts of daily, seasonal and spatial variation in piggery shed dust generation and composition (Banhazi 2011)
- effectiveness of a low cost portable air quality monitoring device (Clements 2011)
- use of passive natural ventilation systems (Ecim-Djuric and Topisirovic 2010)
- human health impacts of dust and associated bioaerosols in piggery air (Li 1997; O'Sullivan 1998; Tan 2004; Schiffman *et al.* 2005; Hiel 2009; Sowiak 2012; Hawley 2015).

Table 7 – Performance Data for the Control of Particulate Emission from the Piggery Industry

Source	Technology	Target Emission Percent Reduction (PM)
Animal Housing	Barriers	60*
	Biofilters	78*
	Landscaping	45*
	Oil Sprinkling/Spraying/Additives	70*
	Scrubbers	67*
	UV Light	16*
Manure Storage and Handling	Diet Manipulation	83*
	Landscaping	49*

Source: *Maurer *et al.* (2016)
Target Emission % Reduction Calculated over All Scales

The experience from pigs and poultry shows that dust can be controlled when using fully-covered housing. Cattle livestock buildings are common in northern Europe, and studies focusing on the control of dust emissions from livestock buildings have been conducted in the Netherlands (Takai *et al.* 1998; Zhaoa *et al.* 2009; Winkel *et al.* 2015), England, Denmark and Germany (Takai *et al.* 1998).

By using an appropriate stocking density and bedding, the pen surface in a building could be maintained at a moist condition all year round so that dust is not generated. While this may be technically possible, this is not an economic solution for Australian feedlots. Fully-covered feedlots are only viable in certain climatic situations. Examples are in south-east Asia where high rainfall precludes open feedlots or in high latitudes such as Canada where very cold winter conditions apply.

Similarly, manure-dust generated from cattle handling yards could be eliminated by substituting open yards with fully-covered facilities but with a corresponding cost penalty.

Photograph 12 – Solid-set sprinkler in feedlot pen

Photograph 13 – Solid-set sprinklers in cattle handling yards

4.4.3 Engineered and other physical controls

4.4.3.1 Buffers

The most common solution to dust hazard when dust elimination is not possible is to provide a buffer (separation distance) between the dust source and the community. Buffers are not a solution for livestock or feedlot staff and contractors.

Dispersal over a sufficient buffer distance is an effective mechanism for reducing PM emissions to acceptable levels. The National Guidelines for Beef Cattle Feedlots in Australia (MLA 2012b) provide an outline of the accepted practices for the mitigation and management of fugitive dust from beef feedlots. These guidelines provide "generally acceptable principles for the establishment and operation of feedlots based on the best technical information available at the time of publication" (3rd Ed; MLA (2012b), p. vi). They support industry members to implement the *National Beef Cattle Feedlot Environmental Code of Practice* (2nd Ed); (MLA 2012a), which are "intended to provide nationally consistent requirements under state regulation for lot feeders and administrators regarding the environmentally relevant aspects of the establishment and operation of beef cattle feedlots" (p. iii).

Separation distances prescribed by the National Guidelines for Beef Cattle Feedlots in Australia (MLA 2012b) are based on odour issues, although these have been assessed by NSW EPA (n.d.) as also providing adequate dispersal distances for PM contaminants.

Buffer distances are tailored to account for variations in site characteristics (e.g. vegetation cover and topography; and meteorological and climatic conditions) and in the sensitivity of the receiving community. Much of the US feedlot industry is located on the Great Southern Plains at elevations above 1,000 m. These regions are particularly sensitive to temperature inversions (see Section 3.4) which form in the evenings under low wind conditions and severely restrict plume dispersion (Casey 2016).

Effective separation distances allow sufficient space for restricted plume dispersion and for natural attenuation processes to reduce dust concentrations to levels suitable for the surrounding community. These attenuation processes may include:

- dispersion, lessens peak dust concentrations in any one place.
- gravitational settling, large particles greater than 10 µm are primarily removed through gravitational settling (SKM 2005).
- flocculation, fine particles (i.e. 1 µm) have negligible settling velocities (SKM 2005)
- rainout.
- absorption (i.e. on soil particles or vegetation).

Natural attenuation processes are effective in reducing feedlot dust concentrations at downwind receptors, although emissions themselves are not reduced.

4.4.3.1 Windbreaks

Windbreaks and vegetative screens may be used by feedlots to protect the community from fugitive dust emissions (WSDE 1995; MLA 2012b). For the Australian lot feeding industry, mandatory separation distances factor in pre-existing vegetation and topography. However, windbreaks and vegetative screens may be useful in specific applications such as along internal access roads. Since feedlot dust is principally emitted from feedlot pen or road surfaces, windbreaks are generally not viable for the protection of livestock or feedlot workers, though may be able to reduce the impact to neighbours and the surrounding community. Windbreaks close to feedlot pens may have a negative animal welfare outcome due to increasing the risk of heat stress events.

Vegetative Environmental Buffers have primarily been examined in the swine and poultry industries (Tyndall 2008) where they have successfully been used to reduce dust and odour emissions from animal house exhaust fans (Malone *et al.* 2006; Tyndall 2008). Dust accumulation on trees can be significant and for the poultry industry, deciduous trees are often planted in the first row closest to tunnel ventilation fans to reduce tree mortality (Malone *et al.* 2006).

4.4.3.2 Pen design

Effective pen design increases manure removal efficiency (Auvermann 2001; Lorimor 2003) and results in reduced dust generation on-site. Pens that are irregularly shaped make manure removal more difficult and less efficient (Auvermann 2001), although modifying existing feedlot designs may not always be a possibility.

Effective pen design is recommended as a passive dust mitigation strategy. New feedlot operations predominantly construct pens of a ‘regular’ square or rectangular design. Some pens may be irregularly shaped due to site topography and drainage considerations, although this is less effective for edge-to-edge manure removal (Auvermann 2001; Lorimor 2003) and may result in increased dust emissions.

4.4.3.3 Bedding materials

Bedding material may be used to help ease cattle foot problems and to maintain cattle feed intake. Due to high costs in the range of $50-60 per head for woodchips (if not recycled), bedding is typically only suitable for high value cattle, particularly those close to slaughter. A secondary benefit of bedding material is improved dust suppression, although this is unlikely sufficient to justify the use of bedding alone. Alternative bedding materials such as straw may be more cost effective alternatives when compared to woodchips. Dust suppression from bedding material is mediated through reduced evaporation and reduced cattle hoof disturbance on pen surfaces.

4.4.3.4 Water curtains

Water curtains are an emerging secondary dust suppression technology which reduce airborne PM concentrations. This technology has not widely been adopted by the lot feeding industry and is considered to have limited applicability.

Water curtains have been trialled with some success for the cattle lot feeding industry although there are concerns regarding water use efficiencies. A small scale experiment by Auvermann *et al.* (2003) demonstrated that water curtains were able to remove 77% of TSP from the air. Whilst these results are encouraging, water use efficiencies were poor and not appropriate for practical applications (Auvermann *et al.* 2003). In response to this, Auvermann *et al.* (2003) designed a similar system capable of removing up to 40% of TSP for a range of 100 m downwind. These results were based on just two sampling events which were deemed insufficient for statistical analysis. The results obtained (which require further verification) indicate the system would have similar water usage requirements to conventional solid-set sprinkler systems (Auvermann *et al.* 2003). Further design optimisation may see increased TSP removal efficiencies, though effectiveness may be limited to periods when winds are light and atmospheric mixing is minimal (Auvermann *et al.* 2003), i.e. during temperature inversions. Indeed, recent correspondence with Dr Ken Casey has confirmed that three feedlots in the US in areas susceptible to inversions and restricted plume dispersion have already constructed water curtains to mitigate dust emissions (Casey 2016). Further discussions regarding the use of water curtains with Dr Brent Auvermann concluded that they are not an effective approach (Auvermann 2016), and the small scale experiments conducted by Dr Auvermann himself (Auvermann *et al.* 2003) do not justify an alternative conclusion. Dr Auvermann concludes that water curtains currently require high capital and operating costs, and these costs may be more fruitfully used for other dust-control measures (Auvermann 2016). Photograph 14 shows water droplets raining down from a water curtain strip dust from the air on the windward side of a feedlot near Hereford, Texas, USA.

Photograph 14 – Experimental water curtain at Texas feedlot

(Texas Agricultural Experiment Station photo by Kay Ledbetter)

4.4.4 Administrative controls

There are numerous administrative controls that can be used to minimise the hazard of manure-related dust. These controls should be incorporated into standard operating procedures for the feedlot. The development of dust management plans may provide detailed site-specific advice on dust management strategies (WSDE 1995). The Washington State Department of Ecology (1995) provides an excellent guide for setting up a feedlot dust management plan.

4.4.4.1 Time of day controls

As noted in Section 3.4, the time of day when dust is created has a significant bearing on its dispersion and hence, impact on the community. The timing of manure-related dust creation can be either controllable (i.e. dust from animal handling, pen cleaning and manure spreading) versus uncontrollable (animal play, wind driven). Photograph 5 shows dust caused by manure spreading. However, the impact of this dust could be reduced by requiring that manure is only spread in the middle of the day on sunny days (Class A stability). Similar controls are usually recommended for effluent irrigation for the same reason. However, the requirement that all cattle handling should occur in the middle of the day is probably unrealistic as it may lead to animal welfare issues (heat stress).

4.4.4.2 Time of week controls

As with effluent irrigation, community nuisance can be minimised by only undertaking controllable activities on days that will minimise impact on the community. Hence, spreading of manure may be avoided on weekends and public holidays when the public is more likely to be outdoors and using nearby roads.

4.4.4.3 Wind direction controls

Operating procedures can specify that manure spreading should only occur on fields where the prevailing wind on that day will not blow dust towards a neighbouring house or public road.

4.4.4.4 Climate prediction controls

Modern weather predictions have significantly improved such that careful monitoring of climate forecasts can be used in dust management. For example, if heavy rainfall is forecast in a few days, it may be inappropriate to apply water to pens (or roads) as this would be a waste of valuable water and may lead to overly-wet surfaces.

4.4.4.5 Feed management

Improved feed quality through selective breeding, genetic improvement, and increased grain digestibility through steam flaking has significantly improved the feed conversion efficiency for feedlot cattle in Australia (Zinn 1993; Zinn *et al.* 1996; Zinn *et al.* 2002). Improved feed management through greater feed conversion efficiency results in reduced manure excretion, which, in turn, should reduce the potential for dust generation. The potential for odour generation in Australian feedlots has also been reduced since a lessor proportion of microbial digestible material remains in the manure due to improved cattle digestion.

Altered feed management regimes may also be effective in reducing dust emissions in cattle feedlots. Cattle activity or play in feedlot pens, especially when surface moisture is low, can result in increased dust emissions (WSDE 1995; Rahman *et al.* 2008; Bush *et al.* 2014). Concentrations of PM in cattle feedlot pens is generally greatest at dawn and dusk when animal activity is highest and air movement is the most stable (Sweeten *et al.* 1988). Altering feeding regimes during these times may reduce dust emissions by replacing active periods with periods of eating and ruminating (Rahman *et al.* 2008).

4.4.4.6 Administrative controls for Q-fever

Q-fever infections may effectively be eliminated from cattle feedlots through vaccination. Vaccination is the most important protection against Q-fever (Work Cover Queensland 2016) and is close to 100% effective, although the duration of protective immunity is unknown (Queensland Health 2010). By excluding unvaccinated people from working at cattle feedlots, the risks of Q-fever infections can effectively be eliminated. Unvaccinated visitors are often permitted to enter cattle feedlots, although they are generally required to wear PPE (see below). Other strategies such as engineered or physical controls (see Section 4.4.2.1) may reduce the concentrations of potentially infectious airborne particulates, which may reduce the risk of Q-fever infection for unvaccinated visitors.

Feedlots should develop workplace procedures to address vaccination of feedlot staff and requirements for visitors (vaccination or PPE).

4.4.5 Personal protective equipment (PPE)

The use of PPE by feedlot workers, specifically dust masks (Photograph 15) and eye wear (wrap-around sunglasses) may assist with minimising dust inhalation or eye irritation and reduce the impact to human health. For successful use, masks must conform to Australian Standards for respiratory protective devices (AS/NZS 1716). Dust masks should be fitted correctly following the manufacturer's instructions, which includes fitting both elastic bands behind the head, if two bands are available (see Photograph 15).

In the US, feedlot workers (i.e. pen riders) typically keep bandanas around their necks and use them occasionally over their noses and mouths when dust concentrations are high. Correspondence with Dr Auvermann suggests that the effectiveness of this approach has not been evaluated in any sophisticated way (Auvermann 2016).

Photograph 15 – Correct use of dust mask

Source: Tri-Tech Forensics (2016)

5 Traffic-related dust

5.1 Traffic-related dust generation

Dust emissions from unpaved road surfaces can be significant sources of air pollutants, and depending on the feedlot locality and design, may exceed dust generated from feedlot pens (see Section 3.3). Considerable amounts of dust are generated by feed trucks travelling along unpaved feed alleys and roads (Photograph 16). Gravel turnarounds can be a considerable source of dust.

Photograph 16 – Dust generated by feedlot traffic

5.2 Components of traffic-related dust

Some Australian lot feeders commented that traffic-related dust is usually a finer material than manure-related dust. As such, it hangs in the air for longer periods. This fine dust is the "bulldust" that builds up beside gravel roads.

Dr Andrea Clements conducted her PhD on the identification and composition of fine and coarse particulates from soil, road dust and cattle feed lot material (Clements 2012). Results from a year-long study in Pinal-County, Arizona, found mass concentrations of coarse PM_{10} dust were on average 5 times higher than fine $PM_{2.5}$ particulates. On a regional scale, Clements noted that approximately 10% of PM_{10} dust falls within the $PM_{2.5}$ size category.

Elemental analysis of crustal source material (i.e. originating from the earth's crust) was undertaken, and was compared with measured dust components. Studies found the zone of influence around a specific dust emitter to be approximately 100 m (Ashbaugha *et al.* 2003), which suggests that dust components take on the characteristics of the nearby source material. Common elements in crustal sources included Al, Ca, Fe and Mg. Ca^{2+} and SO_4^{2-} were found to be more common from unpaved roads surrounding feedlot pens, rather than the pens themselves. Road dust also contains a range of organic components from plant material and traffic-related emissions, including tyre wear (Rogge *et al.* 2012).

It is interesting to note that fine $PM_{2.5}$ dust remains airborne for longer and has the potential to travel greater distances. For this reason, $PM_{2.5}$ dust had less of a resemblance to crustal materials (30%) in Clement's study, indicating the components of $PM_{2.5}$ dust are more complex and may be more difficult to estimate.

5.2.1 Traffic-related dust generation rates

Detailed road dust statistics from Australia are unavailable since the NPI only estimates $PM_{2.5}$ and PM_{10} emissions, rather than TSP (NPI 2016). However, the *National Air Quality and Emissions Trend Report* (1997), as cited by Frazer (2003), states that unpaved roads account for more than 10 million tons of PM emissions from the United States each year.

Numerous studies have developed emission factors for the calculation of dust from unpaved roads, although these emission factors need to be quite complex due to variability in vehicles, vehicle speeds and road characteristics (SKM 2005). Final emission factors for a given fugitive source operation are usually derived as the mean of individual emission factors (USEPA, 1998), which may show some variability.

Equation 1 and Equation 2 show the latest US EPA (2006) AP-42 emission factor calculations for unpaved industrial sites (Equation 1) and unpaved publicly accessible roads (Equation 2).

Equation 1 $$E = k\,(s/12)^a\,(W/3)^b$$

Equation 2 $$E = k\frac{\left(\frac{s}{12}\right)^a\left(\frac{S}{30}\right)^d}{\left(\frac{M}{0.5}\right)^c} - C$$

(Source: Equations adapted to SI units from US EPA (2006))

Where k, a, b, c and d are empirical constants, see US EPA (2006).

E = size-specific emission factor (kg per vehicle km travelled)
s = surface material silt content (%)
W = mean vehicle weight (tonnes)
M = surface material moisture content (%)
S = mean vehicle speed (kph)
C = emission factor for 1980's vehicle fleet exhaust, brake wear and tire wear.

5.3 Impacts of traffic-related dust

5.3.1 Impacts on livestock

The impacts to animal health from traffic-related dust are similar to those discussed in manure-related dust.

Anecdotally, some feedlot operators have observed a traffic-dust related impact on cattle and have adopted management changes in response. They have noted that starter cattle (those new to the feedlot) rush up to the feed bunk when the feed truck passes. If the road is dusty, these cattle are exposed to a high load of traffic-related dust. Cattle that have been in the feedlot for a longer period are aware of this nuisance and hang back from the feed bunk until the dust settles. Hence, for cattle new to the feedlot, some managers change feeding time and/or water roads in front of new cattle to manage this issue. The other motivation for reducing dust impact on starter cattle is the perception that dust is linked to BRD and that starter cattle are more susceptible to BRD. Another strategy developed by feedlot managers involves placing advanced short-fed cattle in pens prone to increased dust emissions. This strategy is undertaken in the view that associated respiratory disorders are unlikely to develop before the cattle are sent to slaughter.

5.3.2 Impacts on employees and contractors

The impacts to human health are similar to those discussed in manure-related dust. Silicosis is a lung disease caused by breathing in silica present in traffic related dust, which is derived from sand, rock, and mineral ores such as quartz. It mostly affects workers exposed to silica dust in occupations such mining, glass manufacturing, and foundry work. Like dust from other sources, $PM_{2.5}$ particulates are highly respirable and have a greater health and safety impact on employees and contractors. Anecdotal evidence from the Australian lot feeding industry suggests that traffic-related dust may contain a finer particle size distribution than manure-related dust (see Section 5.2), although this has not been officially verified.

5.3.3 Impacts on community

Padgett (2008) found that fine dust particles created by a single vehicle could travel at least 100 m away from the source, although most particles (greater than 2.5 µm) tended to travel less than 50 m (Padgett 2008). These results have important implications for the lot feeding industry where dust emissions from unpaved roads have the potential to impact upon the community. The impact of dust from roads within the feedlot complex is handled by providing a sufficient buffer between the feedlot and the community (see Section 4.4.3.1). However, traffic-related dust from internal access roads may be an issue for neighbouring houses or for areas of activity close to internal access roads.

5.4 Traffic-related dust hazard control

5.4.1 Elimination

At a feedlot, traffic-related dust hazard requires two elements to occur. Either of these two elements can be addressed to reduce dust hazard. They are:

1. A source of fine, dry matter with small particle size; and
2. A means for the dust to become airborne, being principally either traffic or wind.

5.4.1.1 Sealing roads

Road sealing (with bitumen) (Photograph 17 and Photograph 18) is clearly the best strategy for the elimination of traffic-related dust. This is an expensive option, but in addition to dust control, some lot feeders report that bitumen sealing reduces wear and tear on feedlot machinery.

5.4.1.2 Road design

The initial road design can be an effective strategy for the mitigation of dust generated from road surfaces. The Victorian Cattle Feedlot Code of Practice (DAEM 1995) specifies that access roads shall be formed, defined, drained and surfaced with an all-weather seal or crushed rock. This code of practice is principally aimed at providing Victorian feedlots with all-weather site access, although may also result in reducing dust generation.

Research from the transportation and mining industries demonstrate the importance of effective unpaved road design for reduced dust generation. The U.S. Department of Transportation (US DOT 2013) presents a good review on effective unpaved road design which is of relevance to the feedlot industry. US DOT (2013) concludes that the key properties influencing unpaved road performance include grading or particle size distribution, the fines content, the clay content, and the material shear strength. Material testing should be conducted on unpaved roads to minimise dust generation capacity and to optimise road maintenance requirements.

Potential dust generating material is generally considered to be less than 75 µm in diameter. For this reason, many unpaved road specifications in the US limit fines content to 5% for dust mitigation purposed (US DOT 2013). This strategy may significantly reduce dust generation on unpaved roads, although research by US DOT (2013) shows that low concentrations of fines (i.e. <10 %) indicate the road may be prone to corrugation and may require regular grader maintenance. Research by Thompson and Visser (2007) from the mining industry has also shown that without fines, haul roads become loose, stony, and pose the potential for tyre damage and high rolling resistance. Thompson and Visser (2007) concludes that some fine material is required to bind the larger size fractions together, which improves soil cohesion and reduces road erodibility. Rates of fine materials (<75 µm) in unpaved roads should be optimised (i.e. between 10 – 20 %), as high fine concentrations (i.e. >20 % below 75 µm) may cause roads to become dusty when dry and slippery when wet (US DOT 2013). The US DOT (2013) supplies further information for optimising road design based on grading analysis, plasticity tests and bar linear shrinkage and strength tests.

5.4.1.3 Road wetting – clean water

The use of water trucks on unsealed roads to suppress dust is the most widely used dust elimination method (Photograph 19 and Photograph 20). Whilst effective, water will evaporate quickly and applications may need to be re-applied frequently. The water allocations available to individual feedlots will also determine if this is a viable option.

5.4.1.4 Road wetting - effluent

Effluent from the feedlot holding pond has been used for dust control on roads. Amosson *et al.* (2006) noted that effluent may be recycled for this purpose. In the US, this practice is not commonplace due to public perception concerns, and water may also be limiting from these structures during summer (Casey 2016). There could be a workplace issue with staff inhaling pathogens in feedlot effluent, but this should be a low risk if the effluent is applied close to the road surface with minimal aerosol mist (Photograph 19 and Photograph 20). Indeed, Loneragan and Brashears (2005) has shown that using retention pond water as a method to control dust at the pen surface did not affect animal performance nor was there an effect on pathogen carriage (E. coli O157 and Salmonella spp. in slaughtered animals). Several Australian lot feeders noted that they use effluent to supress dust on feed roads. Effluent water could further improve dust suppression through the generation of a hard crust from the entrained salts, suspended sediments and organic materials. This is an area of limited research, although research by Halliwell *et al.* (2001) found that continuous application of suspended organic solids from cattle effluent caused the formation of restrictive layers near the soil surface. Whilst this surface sealing was undesirable for the effluent irrigation systems investigated by Halliwell's study, the formation of surface crusts may be beneficial for dust suppression on unpaved roads. Interestingly, synthetic effluent containing no suspended organic particulates did not promote surface sealing.

Cattle effluent from the Australian feedlot industry contains high concentrations of calcium, magnesium and sodium (see Table 8), which may also promote the formation of surface crusts, leading to reduced dust generation. Unfortunately, research has not been conducted in this area, although high sodium is measured by high sodium adsorption ratio (SAR) which is known to have a negative impact on soil through surface sealing. It is not known at what point surface sealing may become apparent, although SAR values as low as three can cause dispersion and soil structural problems in low electrolyte solutions (Rengasamy *et al.* 1984), as cited by Hazelton and Murphy (2007). Fig. 14 details the relationship between electrical conductivity (EC) and SAR. It can be seen that with EC increasing above 10.0 dS/m, SAR starts to become quite high, and this may promote surface sealing of unpaved roads.

Research from the mining industry shows that salts (particularly chlorides and bicarbonates) are regularly applied to haul roads. Salts reduce dust generation by forming a hard crust on the surface of the road (Kissell 2003). Crust formation is enhanced through the presence of bicarbonates, which cause calcium and magnesium from the soil and water to precipitate as insoluble carbonates (NSW DPI 2014). The environmental impacts of adding salt to unsealed feedlot roads is expected to be minimal as any excess salt is likely to be collected in the controlled drainage area, and will not be directly released into the environment.

Salts are also thought to suppress dust by increasing roadway surface moisture by extracting moisture from the atmosphere (Kissell 2003). An important consideration is that high sodium concentrations contained in cattle effluent water may promote soil dispersion, which may cause erosion to unpaved roads. Dispersed clay particles may, however, help to clog soil pores, creating a surface seal (USDA 2008), which may reduce dust generation in the short term. Whilst excess sodium may promote soil dispersion, applications of sodium chloride (brine) have directly been applied to unpaved roads in the US for dust suppression purposes (US DOT 2013).

Table 8 **– Effluent Quality in Feedlot Holding Ponds**

	Units	No. of samples	Mean	Median	Maximum	Minimum
Total Nitrogen	mg/L	175	220	165	1095	25
Total Kjeldahl Nitrogen	mg/L	173	218	153	1095	23
Ammonia	mg/L	99	115	69	861	0
Ammonia Nitrogen	mg/L	99	89	53	670	0
Nitrate	mg/L	101	10.1	1.0	305.0	0.1
Nitrate Nitrogen	mg/L	96	2.3	0.2	68.8	0.0
Nitrite	mg/L	19	1.7	1.0	16.8	0.0
Nitrite Nitrogen	mg/L	20	0.5	0.3	5.1	0.0
Total Phosphorus	mg/L	171	71	56	387	2
Phosphate-P	mg/L	102	17	10	133	0
Phosphate (PO_4)	mg/L	93	52	30	407	1
Phosphate P/Total P	-	94	31%	26%	91%	2%
Potassium	mg/L	122	1092	796	6390	21
pH	-	135	8	8	10	7
Electrical Conductivity	dS/m	187	7.8	6.9	37.8	1.0
Total Dissolved Ions	mg/L	60	6941	5552	37955	1134
Total Dissolved Solids	mg/L	57	4915	4329	18644	1002
Calcium	mg/L	114	126	113	597	13
Magnesium	mg/L	114	118	90	805	2
Sodium	mg/L	114	494	201	6700	12
Sodium Absorption Ratio	-	119	7.1	3.5	65.8	0.5
Chloride	mg/L	110	1261	806	12839	95
Sulphate	mg/L	51	74	40	378	1
Total Hardness	mg/L	61	943	838	3435	85
Temporary Hardness	mg/L	47	913	790	3435	85
Bicarbonate Alkalinity	mg/L	56	2105	1860	7100	206
Carbonate Alkalinity	mg/L	56	102	2	1820	0
Free Carbon Dioxide	mg/L	48	66	26	770	0
Hydroxide Alkalinity	mg/L	47	1.7	2.0	2.0	0.0
Residual Alkalinity	mg/L	54	22.4	18.5	110.0	0.0
Saturation Index		46	1.8	1.9	3.0	0.2
Total Alkalinity	mg/L	62	2082	1845	8920	168
Aluminium	µg/L	43	989	850	3435	47
Boron	µg/L	52	2180	1870	7100	56
Copper	mg/L	52	142	2	1820	0
Free Residual Chlorine	mg/L	44	81	25	770	0
Silica	mg/L	43	2.7	2.0	47.0	0.0
Total Iron	mg/L	50	24.1	18.3	110.0	0.0
Total Manganese	mg/L	42	2.9	2.0	46.0	0.2
Zinc	µg/L	58	2173	1847	8920	62

Source: FSA Consulting (2012)

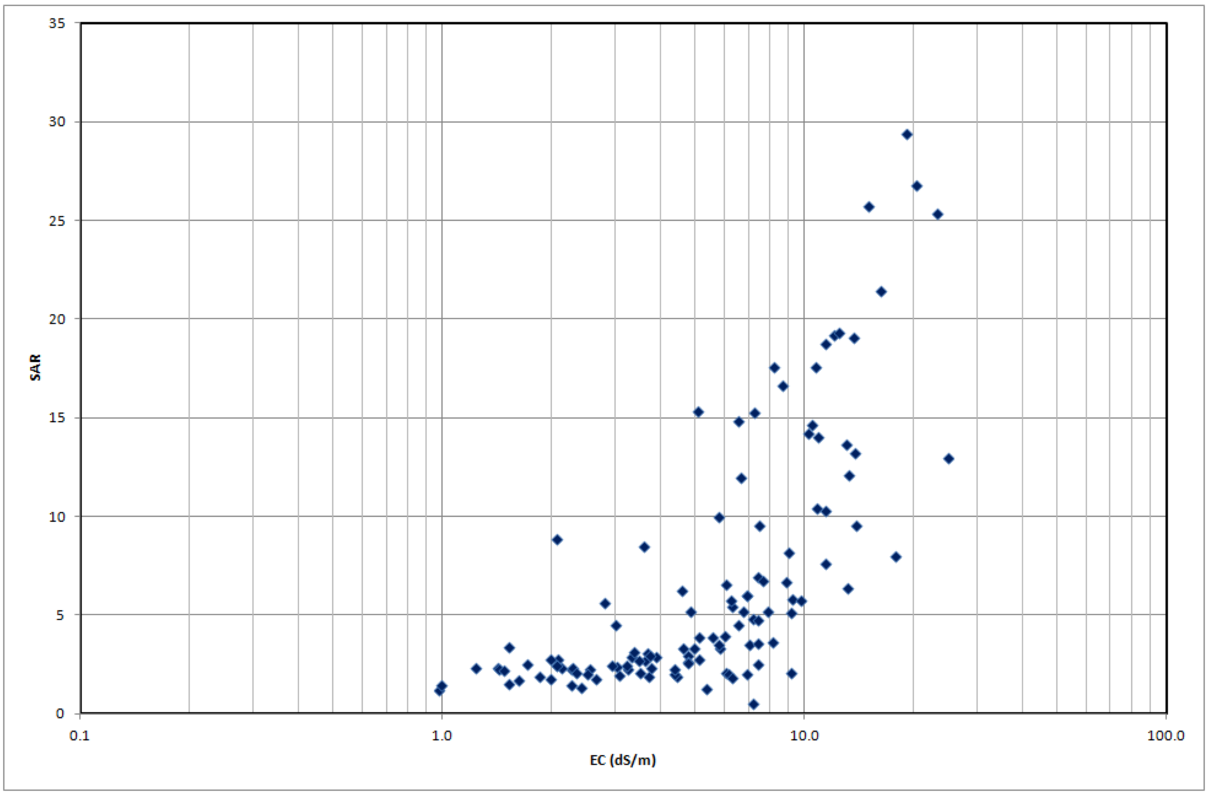


Fig. 14 – Relationship Between EC and SAR for Feedlot Effluent

Source: FSA Consulting (2012)

5.4.1.5 Oil, including spent motor oil

Although it has been done in the past, mineral oil and oil products (including spent oil) should **not** be used for dust control as it may wash into surface or groundwater. Dust from oiled road may also be inhaled by staff with negative consequences. Spent oil is a regulated waste product under Schedule 2E of the Queensland Environmental Protection Regulation (2008) and needs to be disposed of appropriately. Additionally, if oil is applied to an unsealed road with a high silt or clay content, a slick road surface may be produced.

As an alternative to mineral oils, vegetable oils such as soybean, cottonseed and canola oil may be used for dust control. Unlike mineral oils, these substances are environmentally safe and biodegradable, although they evaporate quickly and are typically short lasting (GRT 2015). Section 5.4.1.4 describes additional salts and dust suppressants which are used in the road industry. Salts (particularly chlorides and bicarbonates) are regularly applied to haul roads and section 5.4.1.4 discusses whether additional dust suppression benefits could be attained from effluent water which has a high salt content (see
Table **8**).

Photograph 17 – Sealed feed road eliminates dust to cattle when feeding

Photograph 18 – Bitumen sealed roads eliminate traffic-generated dust

Photograph 19 – Water truck operating on gravel feed road

Photograph 20 – Feedlot water truck

5.4.2 Substitution

Given that the whole operation of a feedlot is based around the movement of feed, livestock, pen cleaning equipment and various front-end loaders, bobcats and tractors, it seems unlikely that there is any substitution option available for traffic-related dust.

5.4.3 Engineered and other physical controls

5.4.3.1 Windbreaks

As discussed in Section 4.4.3.1, windbreaks along roads may assist with reducing the impact of traffic-related dust from internal access roads to surrounding community amenity.

5.4.3.2 Air-tight vehicle cabins

An engineering solution to traffic-related dust for feedlot staff and contractors could be the mandatory requirement that all vehicles have air-tight, air-conditioned cabins with dust filters. This recommendation has been taken from the mining industry where many enclosed cabs on rock drills and bulldozers do not provide adequate dust protection (Organiscak and Page 1999), as cited in Kissell (2003).

5.4.4 Administrative controls

There are numerous administrative controls that can be used to minimise the hazard of traffic-related dust. These controls should be incorporated into standard operating procedures for the feedlot.

5.4.4.1 Vehicle operation - speed

Strict speed should be enforced (i.e. 20 or 40 km/h) on unsealed roads as increased speed significantly increases dust emissions (Division of Air Quality 2016). In Australia, licensing conditions in Western Australia may prescribe maximum speed limits of 20 km/h for feedlot dust mitigation (Government of Western Australia 2012). Photograph 21 shows a typical speed limit sign at an Australian feedlot.

5.4.4.2 Timing of traffic

As with manure-related dust, the timing of dust creation can be used to reduce the impact on the community. Time of day and day of week can be specified to reduce dust nuisance to neighbours. However, this is not always possible when transporting livestock as animal welfare considerations may be more of an issue.

5.4.4.3 Strategic road watering

Due to the issue of starter cattle rushing up to the feed bunk at feeding time, some lot feeders adopt a system of increased feed road watering in areas where starter cattle are present.

5.4.5 Personal protective equipment (PPE)

As per PPE recommended for manure-related dust, dust masks and eye wear, may assist with minimising dust inhalation or eye irritation and reduce the impact to human health.

Photograph 21 – Speed limits reduce traffic-related dust

6 Feed-related dust

6.1 Feed-related dust generation

Feed-related dust may be generated by grain processing, hay grinding, loading commodities into the feed truck, mixing feed and delivery of feed into the feed bunk.

6.2 Components of feed-related dust

In the US, dust emitted from grain handling facilities may comprise approximately 70% organic materials, 17% free silica (silica dioxide), and 13% other materials, including contamination from dust and debris (Billate *et al.* 2004). Research from US grain handling facilities show mean PM_{10} particulates comprise approximately 25% of total dust, with fractionation showing approximately 17% of PM_{10} particulates fall within the $PM_{2.5}$ size category (Boac *et al.* 2008). These results appear roughly in line with dust derived from other sources, i.e. feedlot manure.

In similarity to manure-related dust, the components of feed-related dust differ from the parent material. Differences are mainly due to increased ash and trash content in the dust, compared to the whole grains (Lai *et al.* 1981; Martin 1981). Ash and trash materials are collected during grain harvesting, and contents of these vary to reflect harvest conditions (Martin 1981). Due to increased ash and trash content in the dust, protein content is typically lower than in whole grains, although ash free proximate analysis of dust were similar to their respective values in grains (Martin 1981). Dust may contain increased concentrations of K, Zn, Fe, Cu, Ca and Mn (Lai *et al.* 1981), which may be due to contamination with trash and soil during harvest. The components of dust derived from different grain types will differ, although these components will typically be a product of the parent grain and the harvest conditions.

6.3 Impacts of feed-related dust

6.3.1 Impacts on livestock

No studies were found that discussed the impacts of feed-related dust on cattle. Feed dust is primarily generated by grain processing and hay grinding which is normally conducted in feed mills away from cattle pens. Dust may also be generated during the delivery of feed into the feed bunk, although this is likely to comprise a very low proportion of overall cattle dust exposure.

6.3.2 Impacts on employees and contractors

6.3.2.1 Health impacts

Safe Work Australia (2011) provides guidelines of 10 mg/m^3 over eight hours (TWA) for nuisance non-specific dust, of which feed-related dust may comprise. There is growing evidence that feed-related dust should not be considered ‘nuisance dust’, and that stricter exposure guidelines should be enforced (Huy *et al.* 1991; Becklake *et al.* 1996).

Like Australia, Canadian exposure guidelines for feed-related dust are set at 10 mg/m^3, although there is some speculation that these maximum exposure guidelines may be set too high (Huy *et al.* 1991). Huy *et al.* (1991) investigated feed dust exposure using personal air samplers for 454 grain elevator workers and 55 civic workers over a 15-year period. This assessment was used to estimate the lifetime risk for worker dust exposure for 20 different job descriptions. Results found workers with estimated average exposure below guideline values of between 4 and 9 mg/m^3 had significantly reduced lung capacity (FEV and FVC). Interestingly, workers exposed to <4 mg/m^3 showed significantly higher lung capacities (FEV and FVC) than workers exposed to higher dust loads (Huy *et al.* 1991). A desktop study by Becklake *et al.* (1996) examined articles published from 1924 to 1993 on the effects of grain dust on the respiratory tract of workers. In similarity to the study conducted by Huy *et al.* (1991), Becklake *et al.* (1996) recommended reducing permissible grain dust exposure levels to 5 mg/m^3 (TWA 8 hours).

In light of these findings, dust mitigation strategies for feed-related dust in Australia should aim to maintain maximum dust exposure guidelines well below maximum exposure guidelines of 10 mg/m^3.

Allergic reactions and asthma are also issues for feedlot staff working around feed-related dust. However, there is generally a low proportion of people with atopy working in the grain industry. Atopy (atopic syndrome) is a syndrome characterized by a tendency to be “hyperallergic”. A person with atopy typically presents with one or more of the following : eczema (atopic dermatitis), allergic rhinitis (hay fever), or allergic asthma. One notable Australian feedlot manager is hyperallergic to sorghum dust. Similarly, people with asthma seem to avoid employment in grain elevators (Becklake *et al.* 1996).

6.3.2.2 Explosion and fire risks to staff

Many instances of grain-dust explosions are reported in the literature. There is clearly a workplace health and safety hazard associated with grain dust for this reason. However, the phenomenon is well understood and all designers of feed mills use various engineering solutions (Section 6.4.3) to minimise the risk.

6.3.3 Impacts on community

Feed-related dust is not reported to have any impacts on the community, as dust generation occurs within feed mills and buffers for manure and traffic-related dust are more than sufficient.

6.4 Feed-related dust hazard control

6.4.1 Elimination

At a feedlot, feed-related dust hazard needs two elements for it to occur. Either of these two elements can be addressed to reduce feed-related dust hazard. They are:

1. A source of fine, dry feed with small particles sizes, and
2. A means for the dust to become airborne being either machinery or wind.

A source of fine, dry feed of small particle size cannot be avoided, since the feed is delivered dry to the feed mill for storage purposes. Experience from the bulk solids handling industry has shown primary dust suppression techniques like water spraying to be more effective than secondary techniques such as dust filtration (Faschingleitner and Höflinger 2011).

Processing dry grain, including dry-rolling, has the potential to create feed-related dust. However, following advice from feedlot nutritionists most feedlots now use wet grain. Techniques like tempering and steam flaking add water to grain which increases grain digestibility and reduces dust generation. Photograph 22 shows dust generated from dry rolled grain. The addition of water significantly reduces dust generation as seen in Photograph 23.

6.4.2 Substitution

Boac *et al.* (2008) examined emission factors and dust generation from different feed sources. Results found that shelled corn particles produced greater dust at significantly finer particle size distribution than wheat. In particular, handling fine corn generated 185 g/t of total dust, whilst handling wheat only generated 64.6 g/t of total dust. Shelled corn isn’t a major feed component for Australian feedlots, although corn is used extensively in the US. Similarly, feed milled on-site could be substituted with a total mixed ration produced off-site.

Substitution solutions of changing grain and/or using off-site processing are not economically viable for most feedlots. Furthermore, this is unnecessary as it is generally agreed that feed-related dust is not a major issue at Australian feedlots.

Photograph 22 – Dust from conveying dry-rolled dry grain

Photograph 23 – No dust from conveying rolled wet grain

6.4.3 Engineered and other physical controls

Systems commonly used in the feed industry to contain dust are:

- Modu-Pulse Bag-house Dust Collectors
- Wet Scrubbers
- Cyclones
- Cyclo-Filters
- Vacuum Units
- Materials convey systems
- Ducting
- Extraction hoods

A number of technologies and strategies are used for the control of dust emissions from point sources, such as those generated from feed production. Point sources are easier to control as emissions are generated from single discrete sources such as exhaust gases which may be channelled through a chimney stack. Concentrated exhaust gases may be treated using a range of particulate control devices including cyclone separators, bag filters, wet scrubbers or electrostatic precipitators prior to environmental release.

Historically, dispersion has been used as an effective strategy for the reduction of contaminants from exhaust gases. Tall stacks are effective in penetrating inversion layers which limit the vertical mixing of air due to temperature gradients created under stable atmospheric conditions. The penetration of these inversion layers allows for greater atmospheric mixing and enhanced dispersal of pollutants. Pollutants are also not affected by wake forces (interference from neighbouring buildings) if the stack height is at least 2.5 times the height of the largest nearby buildings (NSW EPA 2005). Tall stacks would not be recommended for the control of PM pollutants which have effective gravitational settling for particles >10 µm and are unlikely to travel far from the emission source. Gaseous or ultra-fine PM (i.e. 1 µm) which have low gravitational settling rates should be treated prior to environmental release as these are long lived contaminants which have the potential to travel vast distances. Fig. 15 details industrial particulate control devices used by other industries, being cyclone separators, bag filters, wet scrubbers and electrostatic precipitators.

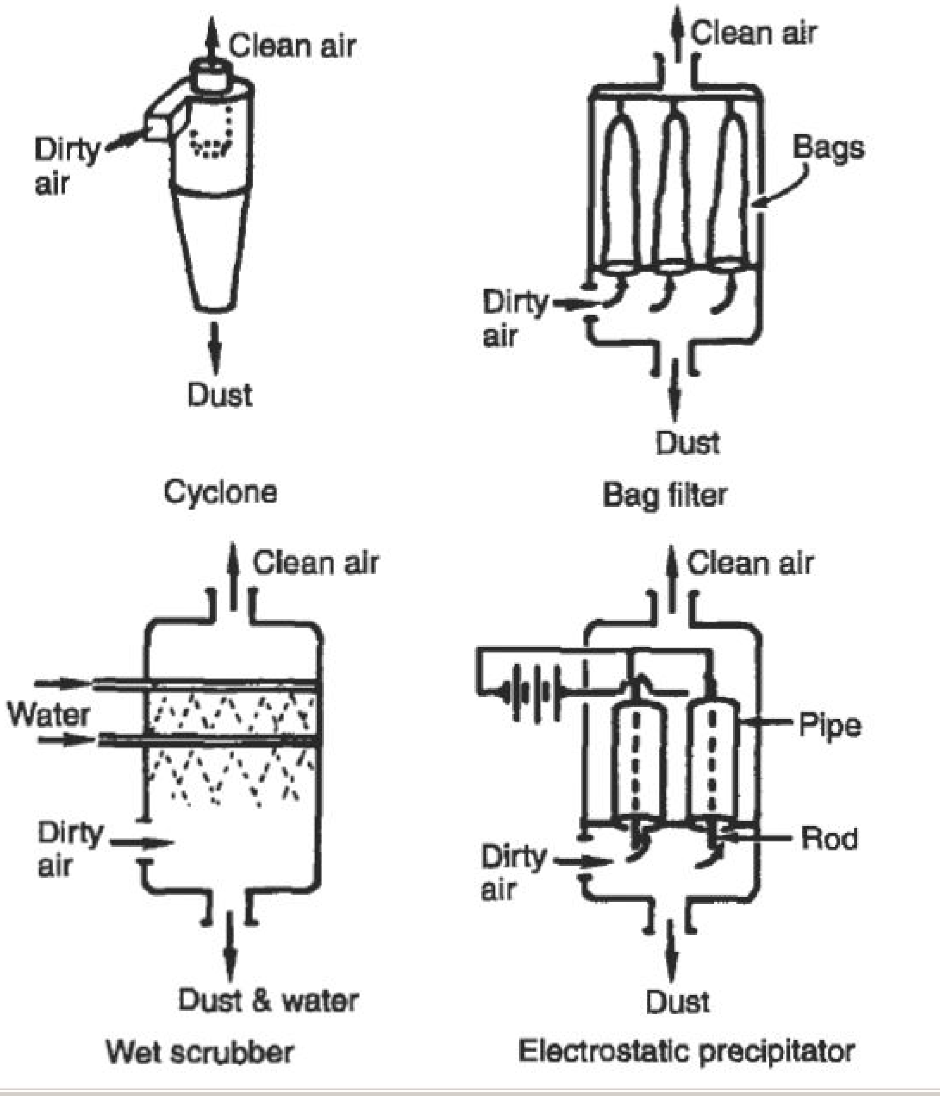


Fig. 15 – Industrial particulate control devices

Source: Weiner and Matthews (2003)

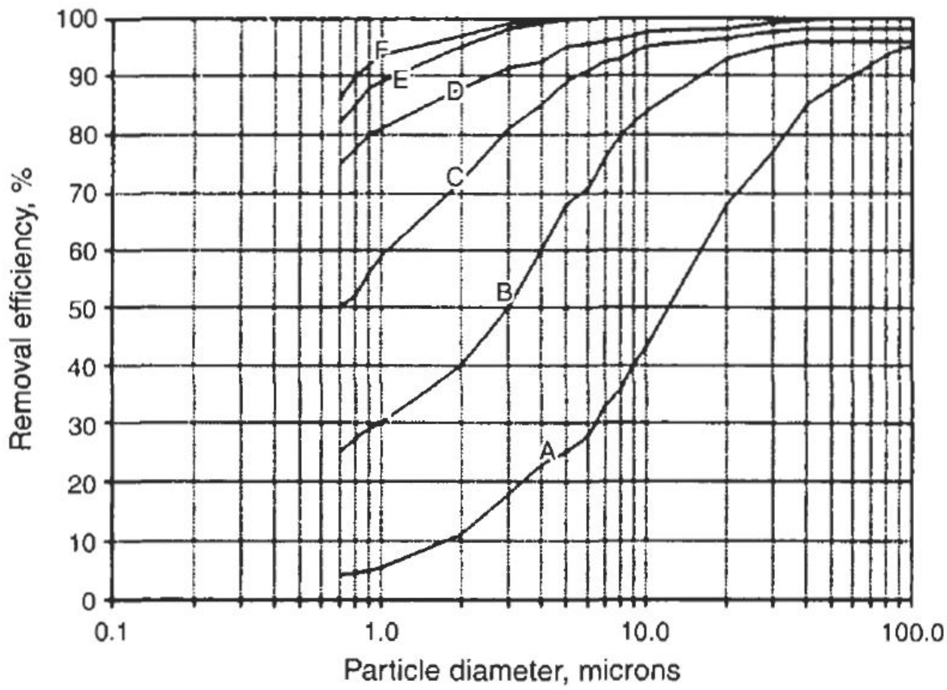


Fig. 16 – Comparison of removal efficiencies for different dust removal options

a. simple cyclone
b. high-efficiency cyclone;
c. electrostatic precipitator;
d. wet scrubber;
e. Venturi scrubber; and
f. bag filter

Source: .Weiner and Matthews (2003)

6.4.3.1 Cyclones

Cyclones work by separating PM by centrifugal (rotational) force. Solid particles are forced to the walls of the cyclone and spiral down the underflow (via gravity) where they are deposited in the hopper for removal. Clean air and gases spiral up through a vortex finder pipe and into the overflow for release. Cyclone separators have relatively low removal efficiencies, although efficiencies can be increased by imparting greater centrifugal force (i.e. high efficiency/dynamic precipitators). Cyclone separators are successfully used in feedlots to reduce dust generation from grain milling operations (see Equation 3).

Equation 3 $F_c = M_{p.} * v^2/R$

The magnitude of centrifugal force depends on the particle mass, the gas velocity within the cyclone, and the cyclone diameter.

Where:

F_c = centrifugal force [N]

M_p = particulate mass [kg]

v_2/R = centrifugal acceleration where v_2 equals particle velocity and R equals the radius of the cyclone [m/s^2].

Source: Davis and Masten (2014) as cited in CQU (2015)

Photograph 24 – Grain scalper and cyclone to remove dust

6.4.3.2 Bag filters

Air is filtered by passing through a fabric bag. PM collects in the bag and is periodically removed by mechanical shaking or reverse flow. Individual bag filtering rates are low and range from 0.5 to 5 m^3/minute (Kanaoka 2006). Due to low filtration rates for individual bags, multiple bags can be assembled into a single unit called a bag house. This allows for high filtration rates and good removal efficiencies across a range of particle sizes. Bag filters are used for a variety of applications and can handle temperatures up to 250 C (Kanaoka 2006). For increased temperatures, cooling systems may be used to prevent exposure of hot gases to the fabric material. Carpenter and Fryer (1990) used a bag filter system which reduced PM concentrations by 50 to 60%, resulting in daily dust collection rates of up to 500 g per 100 piglets. For the poultry industry, bag filters reduced particulate concentrations by up to 72% during field trials in Germany (Mostafa and Buescher 2011). The high volumes of dust collected by bag filters increase cleaning labour requirements and costs for frequent filter replacements (Prairie Swine Centre 1998).

6.4.3.3 Wet scrubbers

Wet scrubbers and biofilters are principally known for their use in ammonia control (Ullman *et al.* 2004b; Van der Heyden *et al.* 2015), although new generation scrubbers (often with added bio-filter or acid scrubber units) are multi-use and are also effective in removing PM concentrations and odour (Melse and Timmerman 2009; Van der Heyden *et al.* 2015; Loyon *et al.* 2016). Venturi scrubbers (common type of wet scrubber) essentially have 100% removal efficiency for particles >5 µm (Vesilind *et al.* 1994) and are an effective dust management technique for indoor animal houses or point sources of pollution. Wet scrubbers would not be suited to outdoor feedlot applications where natural ventilation disperses pollutants over relatively large areas. Wet scrubbers operate in a similar manner to water curtains where dust particles and gases are removed by incorporation inside water droplets which are generated by a fine spray.

6.4.3.4 Electrostatic precipitators

Electrostatic precipitators pass air through high-voltage wires with large negative DC voltage where dust particles become electrically. Removal efficiencies for electrostatic precipitators are high and they can handle large volumes of air/gas, although electricity usage is substantial resulting in high operating costs. Electrostatic precipitators cannot be used with explosive materials due to a risk of ignition. Correspondence with Dr Auvermann suggests that high-grade, dry cattle manure has a non-trivial fuel value, somewhere between those of lignite and coal (Auvermann 2016), and this may present an explosion hazard. This technology has been used for various industries, including for use in boilers and cement kilns, and for houses, offices, hospitals and food processing factories (Mizuno 2000). Electrostatic precipitators have been trialled for use by the poultry industry with initial scoping studies demonstrating dust removal efficiencies of 37 to 79 % (Chai et al., 2009). The collection efficiency of an electrostatic precipitator may be estimated by an empirical equation:

Equation 4 $R = 1 - \exp(-A\, w/Q)$

Where:

- A = area of the collection plated [m^2]
- w = drift velocity of the charged particles [m/s]
- Q = flow rate of the gas stream [m^3/s].

The drift velocity is the velocity at which the particles approach the collection plate. It is analogous to the terminal settling velocity in gravity settling, except the driving force is the electrical charge instead of gravity. The drift velocity can be expressed by:

$w = a * d$ (4–11)

Where:

- a = parameter could be constant for a given system, assumed to be 5 * 105 [sec^{-1}]
- d = the particle size.

The numerical value of w ranges from 0.04 to 0.2 m/s.
Source: Davis and Masten (2014), as cited in CQU (2015)

An article on composting facilities identified equipment maintenance issues (and their associated health and safety concerns if not addressed) related to dust (Spencer and Alix 2006). These issues included bio-fouling (sliming) of ventilation systems and air scrubbers, collapse of ducting due to dust accumulation and fire hazard risk (Spencer and Alix 2006). Environmental impacts on receiving waters of ventilation system cleaning water were also observed through changes in biological oxygen demand (Spencer and Alix 2006). While many of these practices are not relevant for feedlots, consideration of dust implications for equipment maintenance and fire hazard is relevant.

6.4.4 Administrative controls

Administrative controls can manage feed-related dust control practices by only enacting abatement strategies (i.e. scrubbers, air filters, cyclone separators) during times of grain milling and high dust generation. These strategies are energy intensive and may not need be used all the time in a feed mill setting.

6.4.5 Personal protective equipment (PPE)

The PPE options for feed-related dust are similar to those for manure-related dust (see Section 4.4.5.

7 Discussion

7.1 Effect of feedlot dust on livestock

A large amount of dust can be produced in feedlots. This is a complex mix of organic and inorganic particles and is generated in feed preparation and delivery, cattle movement, manure and manure management. Traffic and pen maintenance also contribute to feedlot dust. Dust generation can be an issue for many Australian feedlots and has the potential to impact on the health and safety of employees, the surrounding community and livestock. However, if managed correctly, dust is generally considered to be only a nuisance to employees and the surrounding community.

The impact of feedlot dust on livestock has been thoroughly investigated. A review of literature could not find any evidence to support the hypothesis that the inhalation of large dust particles physically damages the upper airways, which predisposes the animal to colonization of viruses such as IBR virus, and destroys the function of the mucocilary elevator. No evidence could be found to support or contradict this theory.

Dust is made up of inorganic material including a wide range of elements in lung tissue, including silicon, aluminium, titanium, iron, carbon and small amounts of other metals. These are phagocytosed by macrophages and cleared from the lung. The organic component of dust is made up of vegetable particles from grain, hay and feedstuffs as well as bedding, hair and skin scurf. Insects contribute insect parts and mites. Fungi, bacteria and toxins are present in the soil component of pen dust.

The microbiological makeup of feedlot dust was examined in a number of studies. This consists of a large amount of gram positive bacteria, a variety of fungi, no viable gram negative bacteria and varying amounts of endotoxin. All of the bacteria cultured were considered to be non-pathogenic. Cattle manure contains a large amount of gram negative bacteria, these are highly susceptible to heat, UV light and desiccation. They rapidly become non-viable in the feedlot environment. All gram negative bacteria contain endotoxin, this relatively heat stable, biologically active material profoundly affects the immune system. Endotoxin is prevalent in feedlot dust and is considered to be the active material in feedlot dust.

There have been very few controlled studies examining the effects of dust in cattle. Most of the work has used small ruminants (goats or sheep) as the experimental model. Typically, these studies found no changes in ADG, feed intake or final body weight. In some instances, such as Chirase *et al.* (2000), high levels of dust did decrease feed intake in the group previously treated with tilmicosin phosphate.

Exposure to feedlot dust significantly increases rectal temperature 4 to 8 hours after the dust event. This finding was consistent in most studies. Packed cell volume (PCV) and blood haemoglobin concentration decreased following dust events while total white blood cell counts increased. These changes were observed on the first day. Tolerance or immunoadaptation to dust soon develops and these changes were not seen on subsequent days. Smith (2007), used beef calves, did not find any changes in feedlot performance or any changes in rectal temperatures, PCV, blood haemoglobin concentration or total white blood cell counts.

The transient nature of the rectal temperature response is of importance. The fever that is observed during the initial stage of a dust event was consistent and could contribute to confusion over diagnosing acute bovine respiratory disease in instances where rectal temperature is used to confirm the diagnosis (Chirase *et al.* 2004). The study by Purdy *et al.*

(2002c), showed that endotoxin was the cause of the elevated rectal temperatures and the changes in WBC counts.

The pulmonary clearance mechanisms are not affected by dust, respiratory pathogens injected into the lungs were effectively cleared whether or not the animals were subjected to dust (Purdy *et al.* 2003). Dust causes histopathological changes in the lung tissue. Though there is some variation, the changes are a generalised mild alveolar septal thickening and hypercellularility as a result of infiltration with macrophages, lymphocytes and neutrophils. Exudate is found in the terminal airways consisting of neutrophils and macrophages filled with foreign particulate matter and siliceous material. This is not unexpected and demonstrates the normal immune response to foreign material in the lung. These changes occur with or without treatment of tilmicosin. A sub-acute interstitial pneumonia or mild acute exudative broncho-interstital pneumonia was the diagnosis.

There appears to be little evidence to support the hypothesis that the presence of feedlot dust directly predisposes cattle to increased levels of Bovine Respiratory Disease. The research concentrated on short events or short chronic events. There were no studies that looked at continuous long term exposure of dust. There are some gaps evident in the research. Firstly, the physical effects of dust particles on the upper airways have not been examined. Secondly, does the increased exudate found in the lower air way lead to an environment conducive to the proliferation of the main bacterial pathogens of the BRD complex? Thirdly, the response of the immune system to dust events need further investigation. Dust has been considered to be an environmental stress on feedlot cattle. There was no evidence that exposure to feedlot dust significantly increases fibrinogen or haptoglobin concentrations, in the studies reviewed. In these studies cortisol was not included as a hormonal stress indicator.

7.2 Additional research or other actions

7.2.1 Feedlot dust characteristics in Australia

Due to the apparent differences in PM between Australian and US feedlots (Section 4.2.1), more investigations into feedlot dust PM should be undertaken. Data on the chemical analysis of feedlot dust is lacking, and any new dust studies in Australia should include full chemical analyses.

7.2.2 Pen manure removal and dry manure mounding

Research to provide factual data on the benefits of frequent manure removal and/or dry manure mounding (Section 4.4.1.1) should be undertaken.

7.2.3 Modification to pen stocking density

Increased stocking density under dry conditions has been shown to significantly reduce dust emissions (Section 4.4.1.2). However, there are a number of practical issues that need further research and action. These include:

1. A viable means of decreasing available pen area (e.g. by using electric fencing or similar) needs to be developed and trialled for existing feedlots.
2. For new feedlots in winter-dominant rainfall zones, a new pen design should be developed where winter-to-summer pen changes can be made to easily change stocking density. This would require a review of water trough and shade location as well as a sound temporary fencing design.
3. Negotiations with different State regulators would need to occur to allow flexible stocking density management.

7.2.4 Dust management plans

All feedlots should develop dust management plans specific to their site. The dust management plan should be structured using the hierarchy of hazard control discussed in Section 3.2.

7.3 Project delivery

Research priorities were covered by examining over 300 journal articles, industry reports and government documents related to fugitive dust emissions. Articles were sourced from publicly available literature and subscriptions to scientific databases. FSA Consulting contacted a large number of Australian feedlot managers and US researchers who provided practical and technical insights for this report. Special thanks goes to Professor. Brent Auvermann, Dr. Kenneth Casey and Professor Ronaldo Maghirang who are currently conducting research in the US lot feeding industry.

7.4 Project objectives

Meat and Livestock Australia (MLA) recently released a new strategic plan for 2016-2020 (MLA 2016). The key ‘pillars’ of this strategic plan are:

- Consumer and community support;
- Market growth and diversification;
- Supply chain efficiency and integrity;
- Productivity and profitability;
- Leadership and collaborative culture; and
- Stakeholder engagement.

The development of improved dust mitigation strategies aligns with MLA’s strategic direction of consumer and community support, and improved farm productivity and profitability. In deciding whether improved dust mitigation technologies are required, this review seeks to explore whether dust generation has a significant impact on animal health and welfare, and whether improved dust mitigation measures are likely to lead to improved productivity and profitability for the industry.

8 Conclusions/recommendations

This review identified a number of recommendations for feedlot dust research. These recommendations are:

1. Variable stocking densities

Viable means for altering stocking densities between summer and winter require consultation with regulators. Maximum stocking densities are currently limited to 9 m^2/SCU, and stocking densities may further be limited (i.e. to 15 m^2/SCU) based on licensing requirements (MLA 2012b). Variable stocking densities would be in breach of current animal welfare standards if cattle are crowded to less than 9 m^2/SCU, or crowded at densities greater than licensing conditions (i.e. 15 m^2/SCU). Regulations which limit maximum stocking densities for feedlot cattle minimise potential urinary output benefits. Discussions with regulators could be initiated to determine whether increased stocking densities would be appropriate for dust suppression purposes. Research could also be conducted on the potential negative heat load effects of variable stocking densities, and whether these risks can appropriately be managed.

2. Cattle urinary output research

Research investigating cattle urinary output is very topical. In winter dominated rainfall regions in southern Australia, dust emissions can be problematic during the drier summer months. Southern regions tend to have a milder climate and cattle water intake in southern regions may be reduced when compared to warmer northern climates. Reduced water intake results in reduced urinary output, and some southern lot feeders have noted insufficient urinary output for effective pen dust suppression. Increased urinary output may be achieved through variable stocking densities (see Recommendation 1), or through increased water intake. A possible research opportunity exists for methods to increase cattle water intake, such as the addition of salt to feed or water.

3. Water requirements for effective dust suppression

Currently each individual feedlot needs to consider their water availability when considering the use (and frequency of use) for all dust suppression treatments using water. The *National Beef Cattle Feedlot Environmental Code of Practice* (2nd Ed) (MLA 2012a) mentions water requirements for control of dust, and the need for development approval documentation covering a proposed development's expected dust generation, impact and control measures. The code does not supply any specific details regarding recommended timing and duration of sprinkling activities, although this would likely be of benefit to lot feeders. Further guidelines regarding practical trigger points to initiate sprinkling may also be useful. An alternative to using trigger levels could be visual dust assessments, and this appears to be an effective technique in the absence of dust monitoring data.

Preliminary research could be conducted on the water requirements for effective dust control. Research has confirmed the critical threshold for dust control is about 20% (wet basis) (Bonifacio 2013; Bonifacio *et al.* 2015), and water needs to be applied at depth due to disturbance of surface manures by cattle hoof action. As a rough guide, adding 20% water to a depth of 10 cm over an area of 1 hectare would require 200m^3 or 200,000 L of water (assuming no evaporation or runoff). This represents quite a high water usage requirement. Water usage requirements may be reduced through the use of effluent water which may promote surface sealing, or through the use of chemical additives which may lead to improved dust suppression benefits.

An interesting research project in this regard could be the investigation of the relative water use efficiencies for using:

- Clean water;
- Effluent water; and
- Clean water plus additive (i.e. chlorides and bicarbonates)

4. Dust suppression cost benefit analysis

A comprehensive cost benefit analysis of dust suppression techniques is recommended. Although the effectiveness of dust suppression technologies have been well studied, it would appear that the fundamental value proposition of dust control has not been clearly established in published literature. Possible R&D may include comparing sprinkling regimens and pen cleaning frequency on health and performance of feedlot cattle during dry times.

5. Animal health research

Research that should be considered is examination of the effect of particular dust on the upper airway and the implications for colonisation of IBR virus. Examination of whether or not the increased exudate that occurs in the lower airway predisposed to a proliferation of the major BRD pathogens namely *M.Haemolyticia* and *P. Multocida*. Additionally, examining the effects of feedlot dust as a stressor from an endocrine and biochemical perspective.

9 Key messages

9.1 Animal health

Discussions with the Australian lot feeding industry show that dust emissions are of potential animal health concern. Lot feeders appear to be moderately concerned about dust emissions, especially during the early morning and late afternoon periods. There is a lack of research effectively correlating dust emissions with impaired animal health. Nonetheless, lot-feeders generally undertake some form of dust suppression activity, and seek to reduce animal exposure to high dust concentrations.

9.2 Dust mitigation strategies

The generation of dust requires a source of fine material (<75µm), and an energy source for that material to become airborne. Dust may therefore be mitigated by minimising the available source material, or by reducing the ability of the source material to become airborne. Emitted dust may also be captured or dispersed to minimise potential harm.

Removal of source material
The removal of source material for manure-related dust may be conducted through regular pen cleaning. Similarly, dust emissions from unpaved roads can be minimised by road grading which reduces/optimises the fines content of the road. Alternatively, unpaved roads may be sealed which effectively limits dust generation. For feed-related dust, the source material may be processed off-site to minimise dust generation.

Preventing material from becoming airborne
Dust is minimised through reduced wind velocity, or by increasing the energy required for material to become airborne. Wind breaks are effective in reducing wind velocities, and may be suitable dust mitigation strategies for manure and vehicle related dust. Reduction in wind velocities may increase cattle heat stress and this may require further evaluation. Windbreaks are generally not applicable for feed milling, which is conducted in an enclosed environment. Wind velocities may, however, be problematic when delivering feed into the feed bunk, and lot feeders may deliver feed at times when dust emissions are less of a concern for susceptible cattle.

Water suppression techniques reduce dust generation by increasing the energy required for material to become airborne. Sprinker systems are effective in reducing manure-related dust emissions, although these techniques generally require large quantities of water, and this may be limited in some areas. In similarity to sprinkler systems, water trucks may be used for dust suppression on unpaved roads. Cattle effluent water is a good substitute for freshwater, and is generated in abundance on feedlots. Effluent generation can be increased through increased stocking densities, and this is perhaps one of the most successful and cost effective dust suppression techniques for manure related dust. Effluent water may also be sourced from effluent ponds for application on unsealed roads.

For grain-related dust, steam flaking or water addition to milled grain can significantly reduce dust emissions. Steam flaking improves grain digestibility and also improves animal performance. Suppression technologies like oils and salts also reduce the potential for dust generation, and may be effective for unpaved road surfaces.

Capturing or dispersing emitted pollutants
Techniques for capturing, or enhancing the dispersal of fugitive particulates are limited. Such technologies are most applicable for feed-related dust, where cyclone separators and wet scrubbers may be used. Water curtains have been trialed by the cattle feedlot industry for the suppression of airborne manure and vehicle related dust, although this technology has enjoyed limited success due to high water usage requirements.

9.3 Monitoring

An emission factor of 11.7 tonnes PM_{10} emissions per 1,000 head per year is currently used for manure related dust by the Australian lot feeding industry. This is significantly less than the US emission factor of 17 tonnes PM_{10} emissions per 1,000 head per year. Emission factors are currently not used by the Australian lot feeding industry for the calculation of feed and road related dust emissions. Unfortunately, the monitoring of feedlot dust concentrations cannot readily be undertaken by Australian feedlots (See Appendix A below). Improved monitoring is recommended to better understand overall feedlot PM emission rates from manure, road and feed related sources.

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11 Appendix A – Dust measurement and monitoring

Numerous studies have documented the health and safety effects of feedlot dust emissions on humans and livestock. To safeguard against adverse health outcomes, various state and national guidelines for dust emissions have been developed and effective monitoring is required to ensure these guidelines are being met. Feedlots in NSW and QLD are required to record all community complaints (Lewis 2016b), with environmental monitoring data being used to substantiate the validity of these complaints and to minimise any impacts on the surrounding community. Complaints may relate both to nuisance dust (i.e. >10 µm) and fine particulate materials (<10 µm) which are the most damaging to human and animal health (see Section 4.2.1.

Watts and Tucker (1994) conclude that dust monitoring must account for the following variables:

- Seasonal conditions
- Time of day
- Surface wind speed
- Downwind distance
- Climatic factors affecting dispersion
- Background levels of dust: In agricultural settings there are often high background airborne dust emissions. Strategies such as the C18/C16 fatty acid ratio can be employed to characterise dust originating from cattle feedlots operations (Rogge *et al.* 2006).
- Type of sampling device used

It is noted that dust monitoring techniques have changed over time and techniques are specific to the intended use of the data (see above). Effective dust monitoring may be quite complex and this may be beyond the scope for routine measurement by lot feeders. A list of available dust monitoring techniques is shown below.

11.1 Personal aerosol samplers

Personal aerosol samplers could be used by feedlot staff to assess dust exposure levels. Internationally accepted sampling criteria for aerosol samplers have been developed by the International Organization for Standardization (ISO), the American Conference of Governmental Industrial Hygienists (ACGIH) and the Comit Europen de Normalisation (CEN) for $PM_{2.5}$ and PM_{10} (Görner 2001). The measurement of fine $PM_{2.5}$ and PM_{10} fractions is of particular interest as these are the most likely to cause harm to human or animal health (Aizenberg 2001). Sampling criteria are currently under review and exposure limits are based on assumed inhalability of dust particles. For example, recent research by Brown *et al.* (2013) has suggested that thoracic inhalation has been overestimated with only 50% of particles with a diameter of 3 µm in adults or 5 µm in children being inhalable to the thoracic region.

11.2 Aerosol samplers

Environmental monitoring is assessed using automatic weather stations, and this is standard practice for feedlots in QLD and NSW (Lewis 2016a). Automatic weather stations typically record air temperature, wind speed, wind directionality and rainfall and can be used to model the effects of dust and air pollution on surrounding receptor localities (Lewis 2016a). The specific parameters measured differ based on jurisdictions and specific licensing conditions, although the Department of the Environment (2007) handbook details the methodology for reporting feedlot dust emissions in Australia. The Department of the Environment (2007) handbook requires feedlots to report dust emissions (PM_{10}) if greater than 400 tonnes of fuel is combusted on site per year. The handbook does not otherwise require the reporting of dust emissions from feedlot pen or road surfaces and has recently been updated in 2007 in response to reports of overestimation of actual feedlot emissions.

11.3 Air Samplers

The use of air samplers is a more technical and costly monitoring approach compared to conventional dust deposition gauges. Advantages for the use of air samplers are the targeted measurement of fine dust size fractions ($PM_{2.5}$ and P_{10}), which is of benefit to environmental managers and regulators. Accepted methods have also been developed by Sweeten *et al.* (1998) for the estimation of PM_{10} emissions from TSP concentrations, although these methods are less accurate than direct measurement using air samplers.

Air samplers require basic training to operate and conventional gravimetric methods collect sampled dust on specialised filter paper which is sent away to an accredited laboratory for analysis. Lead times for laboratory analysis does not allow for the collection of real-time data, which gives the facility less guidance when responding to changes in dust emissions. More advanced TEOM samplers allow for the real-time monitoring of PM which may be of benefit to the Australian lot-feeding industry.

Air samplers are not suited to high dust environments where they are prone to becoming overloaded. The use of a cyclone pre-separator has been trialled in these dusty environments with promising results (Zhaoa *et al.* 2009), although high dust loads are less problematic for outdoor cattle feedlots where particulate emissions are more dispersed due to natural ventilation.

$PM_{2.5}$ and PM_{10} samplers employ size selective inlets or pre-separators to remove the particle size classes not being measured (i.e. those greater than 2.5 or 10 µm). Pre-sampler removal efficiencies are not 100%, and the US EPA has developed size selective inlet guidelines of 2.5 µm +/- 0.2 µm for $PM_{2.5}$ samplers, and 10 µm +/- 0.5 µm for PM_{10} samplers. Size selective inlets for PM samplers have been designed based on aerosols with mass medium diameters (MMD) much less than typical feedlot dust. This has been found to result in oversampling bias (Auvermann 2016) which has mathematically been demonstrated by Buser *et al.* (2001). Oversampling bias may result in unequal reporting of PM emissions across industries where MMDs can differ significantly (Buser *et al.* 2001). Correction factors based on MMD can be applied to correct for sampling bias for more uniform reporting across industries (Buser *et al.* 2001; Wang *et al.* 2005).

11.4 Dust deposition gauge

Dust deposition gauges are simple inexpensive instruments for the collection of total PM. They are able to determine whether total dust deposition rates comply with guidelines developed by Safe Work Australia (2011) of 10 mg/m^3 over eight hours (TWA). These guidelines are very similar to the total inhalable dust guidelines for livestock which would equate to 10.4 mg/m^3 if adjusted linearly over eight hours (from 24 hours) (Wathes 1994). The main advantage of using simple dust deposition gauges is that dust levels can simply be determined in-house leading to significant cost saving for the facility.

Below is a guide for calculating feedlot dust emissions using a dust deposition gauge:

Guidelines for human exposure to nuisance dust are 10 mg/m^3 over eight hours (Safe Work Australia 2011). Guidelines for livestock exposure to non-specific inhalable dust are 3.4 mg/m^3 over 24 hours (Wathes 1994).Maximum daily (24 hour) inhalable dust fall for livestock should not exceed 3.4 mg/m^3. The majority of dust emissions should be inhalable (see

Table 3), although dust deposition gauges only measure TSP and are unable to distinguish between the inhalable and non-inhalable components. As such, for this example, guidelines for human exposure to nuisance dust have been adjusted over 24 hours (from 8 hours), giving a maximum daily allowable limit of 3 mg/m^3. This value is slightly below livestock guidelines for non-specific inhalable dust (3.4 mg/m^3).

- Dust deposition gauges typically have relatively small surface areas and a surface area of 61 cm^3 (as used by Kwata (2014)) would result in a maximum allowable daily dust deposition rate of 0.18 mg/m^3 (based on the above formulated guidelines of 3 mg/m^3 over 24 hours, modified from Safe Work Australia (2011)).
- Dust values of 0.18 mg are quite low and may result in weighing inaccuracies. The feedlot may therefore wish to purchase multiple (or larger) dust deposition gauges, or to average dust fall over multiple days. For example, if allowable dust fall is 0.18 mg per day for a 61 cm^3 collection vessel, allowable weekly dust fall would be 1.28 mg which would provide less measurement inaccuracies.

Dust deposition gauges are unable to quantify the proportion of fine particulate materials ($PM_{2.5}$ and PM_{10}) which are the most damaging to human and animal health (see Section 4.3. Livestock exposure guidelines for respirable particles are 1.7 mg/m^3 (TWA over 24 hours), which are exactly half the safe guidelines for inhalable dust (3.4 mg/m^3) (Wathes 1994). Fine dust (<10 µm) generally only makes up a small proportion of feedlot dust, typically reported as between 20 - 40% in US feedlots (Galvin *et al.* 2005) and up to 59% in Australia (Galvin *et al.* 2005). Not all fine dust is respirable with

Table 3 showing that approximately only 50% of particles ≤ 4 µm are respirable. As the respirable component of inhalable dust is likely less than 50%, in the absence of detailed data on PSD, if guidelines for inhalable dust are not exceeded, than guidelines for respirable dust should also be within safe limits.

11.5 New monitoring methods

There is the potential for significant advancement in monitoring methods to allow for the monitoring of ‘real time’ PM concentrations. This poses numerous advantages over current monitoring methods like air samplers where results generally need to be analysed in an accredited laboratory. Due to the complexities of these measurement techniques, consultancies are often employed to conduct air quality assessments and it may take weeks or months before finalisation of monitoring reports. Whilst this may satisfy regulatory requirements, it doesn’t allow for the continuous supply of monitoring data which may be used by the facility to adjust their dust mitigation techniques.

New methods developed by Upadhyay (2008) investigate the use of transmissometers for the estimation of PM concentrations downwind of open-lot livestock facilities. Whilst this research is still in its infancy, it does allow for the collection of real-time data and is of great interest to the lot feeding industry. Correspondence with Dr Auvermann notes that technical limitations of transmissometers currently on the market restrict this method to measuring dust concentrations over relatively long paths (> 750 m) (Auvermann 2016). New methods, as noted in Bush *et al.* (2014) need to be developed for shorter path lengths, and this will allow research studies to more confidently distinguish dust concentrations between treatments. One promising method is the patented approach of (Kwon 2004), which is currently being testing in Texas using custom-designed, high-contrast targets with consumer-grade digital SLR cameras (Auvermann 2016).

Other new methods include TEOM samplers which are similar to conventional gravimetric air samplers in that they are fitted with size selective inlets for the measurement of $PM_{2.5}$, PM_{10} and TSP particulates. Similar to gravimetric air samplers, these may also be prone to the same sampling biases (see Section 4.3). TEOM samplers are a US EPA approved method for measuring PM_{10} concentrations which have been used over the past fifteen years by many US state air pollution regulatory agencies (SAPRAs) (Skloss 2008). Major advantages for TEOM samplers include automated operation, reduced maintenance, and continuous, real-time measurement of PM (Skloss 2008; Wanjura *et al.* 2008), which is not possible using conventional gravimetric air samplers. Major issues associated with using different sampling methods include non-uniform reporting of PM concentrations which can be troublesome for regulatory agencies. For example, although Wanjura *et al.* (2008) reported a significant positive relationship between TEOM and gravimetric TSP samplers, TEOM samplers typically recorded lower concentrations of TSP than gravimetric samplers.

Photograph 25 – Dust sampler used by Galvin *et al.* (2005)

Galvin *et al.* (2005) focused on the use of dust deposition gauges for the measurement of particulate matter deposition. This method was in accordance to AS NZS 3580.10.1-2003 which has since been superseded by AS/NZS 3580.10.1:2016. Galvin also used more modern methods including high volume samplers (TSP and PM_{10}), and real time samplers (DustTrak 8520). DustTrak 8520 is an out of date model and is not included in the list of designated reference and equivalent methods for air sampling (US EPA 2016a). Potential issues with this method include reduced sampling efficiency when wind speeds exceed 35.4 kph, resulting in measurements not conforming to specified PM_{10} monitoring standards (TSI 2005). It is interesting to note that a review of the latest US EPA (2016a) list of designated reference and equivalent methods only included one approved method for real-time particulate monitors (Met One BAM-1022 Real Time Beta Attenuation Mass Monitor; Designation Number: EQPM-1013-209; Method Code: 209).

12 Appendix B – Fact Sheet

Fact Sheets:

1: Sources and characteristics description

2: Hazard hierarchy – how to address

3: Road Dust – how to address

4: Pen Dust – Sprinkler Systems, stocking density

Fact Sheet 1

Summary of feedlot dust sources and characteristics

A large amount of dust can be produced in feedlots. This is a complex mix of organic and inorganic particles and is generated in feed preparation and delivery, cattle movement, manure and manure management. Traffic and pen maintenance also contribute to feedlot dust. Dust characteristics are a factor of the source material, although atmospheric dispersion may result in dust from multiple sources being blended together, giving more complex dust characteristics.

Key messages

- The main sources of dust for Australian feedlots are manure-related, traffic related and feed related dust.
- Manure and traffic-related dust are considered the most significant sources of dust in Australian feedlots, with feed-related dust typically making a minor contribution to overall dust emission rates.
- Manure and feed-related dust contain a high organic matter component, whilst traffic-related dust tends to contain a greater proportion of non-biodegradable inorganic materials.
- Dust from different sources (i.e. manure and traffic related dust) may mix together, and final dust composition may differ from the original source material.

Manure-related dust

Photograph 1 – Manure-Related Dust

Sources

Manure-related dust is derived from manure from pen surfaces, which can be problematic when pad moisture is low (i.e. < 20%), see Photograph 1.

Low pad moisture may be the result of low stocking densities, or low rainfall, particularly during the summer months. These dry conditions increase dust generation, which is aided through wind and cattle movement, cattle handling and manure management.

Characteristics

Manure-related dust contains a complex mix of organic and inorganic particles. Bedding, hair, skin scurf, insect parts, mites, fungi, bacteria and toxins are all components of manure-related dust.

Traffic related dust

Photograph 2 - Traffic Related Dust

Sources

Dust is generated from unpaved road surfaces from wind, feed trucks, and other vehicle traffic. In similarity to manure-related dust, emissions are greatest when surface moisture is low and when fines content is high.

Characteristics

Traffic-related dust contains a high inorganic component. Inorganic components may include abrasive non-biodegradable particulates such as silica which can become deposited deep in the lungs. Organic matter components may also be present from manure and feed related dust.

Feed related dust

Photograph 3 - Feed Related Dust

Sources

Feed related dust may be created through tub grinding feed, depositing the feed into the hopper, and depositing the feed into the feed-bunk. Dust generation is increased if the feed material is very dry, or if wind speeds are increased.

Characteristics

In the US, dust emitted from grain handling facilities may comprise approximately 70% organic materials, 17% free silica (silica dioxide), and 13% other materials, including contamination from dust and debris (Billate et al. 2004). Particle size distribution varies depending on grain type and milling process.

References

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Fact Sheet 2:

Summary of hazard hierarchy – How to address

Hierarchy of hazard control is a system used in industry to minimize or eliminate exposure to hazards. Current dust reduction strategies from within the feedlot industry have been reviewed using a hazard control hierarchy, as was any new or alternative technologies from other industries, such as construction, mining and quarrying. The hazard controls in the hierarchy, in order of decreasing effectiveness are shown in Fig. 1. If the hierarchy of hazard control is followed, dust should only be a nuisance.

Fig. 1 – Hierarchy of dust hazard control

Key messages

- Hierarchy of hazard control is a system used in industry to minimize or eliminate exposure to hazards.
- The hazard controls in the hierarchy, in order of decreasing effectiveness, are:
  - ❖ Elimination;
  - ❖ Substitution;
  - ❖ Engineering;
  - ❖ Administration; and
  - ❖ Personal protective equipment (see Fig. 1).
- If the hierarchy of hazard control is followed, dust from Australian feedlots should not be a health issue to humans or animals and should only be a nuisance.

Elimination

Elimination of the hazard (i.e. physically removing it) is the most effective hazard control. For example, bitumen sealing of all feedlot roads may eliminate dust generated by traffic.

Substitution

Substitution, the second most effective hazard control, involves replacing something that produces a hazard (similar to elimination) with something that does not produce a hazard. For example, substituting the preparation of feed rations onsite to offsite could eliminate feed related dust at the feedlot, with the risk being transferred somewhere else.

Engineered and other physical controls

The third most effective means of controlling hazards are engineered and other physical controls. These do not eliminate hazards but rather they isolate people and livestock from hazards. Capital costs of engineered controls tend to be higher and less effective in the hierarchy. "Enclosure and isolation" creates a physical barrier between personnel and hazards. An example is feedlot employees and contractors only working within air-conditioned tractors and other mobile machinery. Extraction fans can remove airborne dust from feed processing as a means of engineered control.

Administrative controls

Administrative controls are changes to the way people work. Examples of administrative controls include procedure changes, employee training, and installation of signs and warning labels. Administrative controls do not remove hazards, but limit or prevent people's exposure to the hazards. For example, an administrative control to dust on feedlot access roads could be to limit traffic to those times of day when dust is rapidly dispersed, rather than late evenings when dust will remain at ground level and not disperse.

Personal protective equipment (PPE)

Personal protective equipment (PPE) includes gloves, respirators, hard hats, safety glasses, high-visibility clothing and safety footwear. PPE is the least effective means of controlling hazards because of the high potential for damage to render PPE ineffective. Additionally, some PPE, such as respirators, increase physiological effort to complete a task and, therefore, may require medical examinations to ensure workers can use the PPE without risking their health. Dust masks are a form of PPE for feedlot employees and contractors.

Fact Sheet 3:

Summary of road dust – How to address

Traffic related dust is a significant contributor to feedlot dust emissions, although hazards may be effectively managed using the hierarchy of dust hazard control (see Fig. 1). Elimination is the most effective hazard control technique, and road dust elimination may be achievable through the sealing of unpaved roads. Numerous other dust control options are also available, although these may require frequent reapplication, and strategies may have different dust control efficiencies.

Fig. 1 – Hierarchy of dust hazard control

Key messages

- Dust is generated from unpaved road surfaces from wind, feed trucks, or other vehicle traffic.
- Dust emissions are greatest when surface moisture is low and when fines content is high.
- Emissions should be controlled in accordance to the hierarchy of dust hazard control (see Fig. 1).
- Elimination is the most successful dust control strategy and this may be achieved through road sealing.

In accordance with the hierarchy of hazard control (Fig. 1), dust may be controlled by:

Elimination

Road dust can be effectively eliminated through bitumen sealing of feedlot roads (see Photograph 1).

Photograph 1 – Road dust elimination through sealing of unpaved roads

Road design

Effective road design can significantly reduce dust emissions from unpaved road surfaces. Potential dust generating material is generally considered to be less than 75 µm in diameter. For this reason, many unpaved road specifications in the US limit fines content to 5% for dust mitigation purposed (US DOT 2013). This strategy may significantly reduce dust generation on unpaved roads, although research by US DOT (2013) shows that low concentrations of fines (i.e. <10 %) indicate the road may be prone to corrugation and may require regular grader maintenance. Thompson and Visser (2007) concludes that some fine material is required to bind the larger size fractions together, which improves soil cohesion and reduces road erodibility. Fine material (<75 µm) should be optimised to between 10 to 20 % (Thompson and Visser 2007). The US DOT (2013) supplies further information for optimising road design based on grading analysis, plasticity tests and bar linear shrinkage and strength tests.

Road wetting

Road wetting reduces dust generation by increasing the energy required for material to become airborne.

Both clean water and effluent water can be employed for this purpose.

Photograph 2 – Watering unpaved road

Road additives

Road additives may include salts (especially chlorides and bicarbonates), and vegetable oils such as soybean, cottonseed and canola oil. Mineral oils should not be used for dust control purposes in Australia. Spent oil is a regulated waste product under Schedule 2E of the Queensland Environmental Protection Regulation (2008) and needs to be disposed of appropriately. Effluent water contains high salt concentrations and may have added dust suppression benefits. The difference between clean water, effluent water or clean water with an additive (i.e. a water based polymer) in regards to dust suppression has not been investigated.

Substitution

No methods identified

Engineering and other physical controls

Engineered and other physical controls may include windbreaks and air-tight vehicle cabins which physically restricts worker contact with dust.

Administrative controls

Speed restrictions

Effective administrative controls for road dust emissions include speed restrictions (Photograph 3). The Australian lot-feeding industry may enforce speed restrictions of 20 or 40 km/h on unsealed roads (Division of Air Quality 2016; Government of Western Australia 2012).

Administrative controls may also include travel restrictions on unpaved surfaces and weather monitoring for the planning and readiness of appropriate dust controls.

Photograph 3 – Speed restrictions

Personal protective equipment (PPE)

Personal protective equipment may include the use of dust masks (Photograph 4). A specific protection measure for road dust emissions may be the mandatory requirement that all vehicles have air-tight, air-conditioned cabins with dust filters. This recommendation has been taken from the mining industry where many enclosed cabs on rock drills and bulldozers do not provide adequate dust protection (Organiscak and Page 1999), as cited in (Kissell 2003).

Photograph 4 - Dust mask

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Fact Sheet 4:

Summary of manure dust – How to address

Manure-related dust is most likely to be an issue when surface moisture is low (i.e. < 20%). Pen moisture needs to be carefully managed since low surface moisture leads to increased dust generation, and excessive moisture may create odor problems. Surface pen moisture kept to within 25 and 40% is typically recommended for the minimization of dust emissions (Davis *et al.* 1997; Auvermann *et al.* 2000; Lorimor 2003), and this may achieve a balance between dust mitigation whilst minimizing odor generation potential. The maintenance of stable pen moisture requires an understanding of long-term moisture inputs from seasonal rainfall and cattle effluent, and moisture losses though evaporation. Seasonal conditions may create moisture surpluses or moisture deficits, and strategies like variable stocking densities can be employed to increase or decrease pen moisture when required (through increased or decreased cattle effluent application).

Careful moisture management and regular pen cleaning are both considered successful strategies for the reduction of hazards associated with manure-related dust. These strategies have been classed as elimination controls (see Fig. 1), although manure-related dust cannot entirely be eliminated due to continual manure excretion by livestock, presenting an ever-present source material for dust generation.

Fig. 1 – Hierarchy of dust hazard control

Key messages

- Manure-related dust is largely generated by the action of cattle hooves causing dry manure to be broken down into fine particles and become suspended.
- Dust emissions are greatly influenced by animal activity, and emissions are highest when surface moisture is low (i.e. <20 %).
- Emissions should be controlled in accordance to the hierarchy of dust hazard control (see Fig. 1).

- There are no effective manure dust elimination techniques, although frequent manure removal and effective moisture management (including stocking density manipulation) are effective dust control strategies.

In accordance with the hierarchy of hazard control (Fig. 1), dust may be controlled by:

Elimination

Manure-related dust cannot entirely be eliminated, although manure removal and effective moisture management are both effective in significantly reducing the potential for dust generation (elimination controls).

Manure removal

Manure removal reduces the source material for dust generation, although this source material cannot entirely be eliminated due to constant manure excretion. The use of box scrapers is the current best practice for manure removal in Australia (Auvermann 2001; Lorimor 2003; Watts 2016). Box scrapers use a pulled blade which is able to carefully remove surface manures whilst leaving a beneficial layer of thin compacted manure (interface layer) intact (Auvermann 2001).

Fig. 2 – Manure removal during dry conditions

Manure removal activities may increase dust generation during dry conditions (Fig. 2), and very dry manure often lacks cohesion making manure removal more difficult. Anecdotal evidence suggests that manure removal efficiencies are greatest at 30-40% moisture content. Dust generation is also reduced during these conditions.

Moisture management

Water reduces dust generation by holding fine particulates together through ionic bonds. This increases the energy required for materials to become airborne, and is an effective dust suppression strategy.

Research confirmed the critical threshold moisture content for dust control is about 20% (Bonifacio 2013; Bonifacio *et al.* 2015), and water needs to be applied at depth due to disturbance of surface manures by cattle hoof action. Pen moisture can be maintained by reducing evaporation rates (i.e. through bedding material or shades), or by increasing moisture inputs (i.e. through increased stocking densities, or the use of sprinkler systems).

Stocking densities

Increased stocking density under dry conditions have been shown to significantly reduce dust emissions in the range of 80% (Bush et al. 2014). Stocking densities can easily be manipulated by increasing or decreasing the available pen area, i.e. with temporary electric fencing. This will allow the maintenance of high stocking densities during dry conditions when dust loads are likely to be problematic, and reduced stocking densities during times of increased rainfall.

This is an effective low cost dust suppression technique, although this is subject to regulatory approval.

Further research investigating the manipulation of stocking densities as a means for dust control need to consider:

1. A viable means of decreasing available pen area (e.g. by using electric fencing or similar) needs to be developed and trialled for existing feedlots.
2. For new feedlots in winter-dominant rainfall zones, a new pen design should be developed where winter-to-summer pen changes can be made to easily change stocking density. This would require a review of water trough and shade location as well as a sound temporary fencing design.
3. Negotiations with different State regulators would need to occur to allow flexible stocking density management.

Comparison of sprinkler systems versus stocking density management

In similarity to increased stocking densities, sprinkler systems suppress dust by helping to maintain ideal pen moisture conditions. Unfortunately, very few feedlots in Australia have excess clean water availability and large quantities of water are required to successfully and consistently eliminate dust from pens.

Water availability constraints are very significant for sprinkler systems, and this appears to be the main factor limiting their use. These constraints are less applicable for stocking density manipulation where increased manure (water) inputs are a byproduct of increased cattle densities. Increased stocking densities do not require an overall change in cattle numbers, meaning that overall water consumption will remain largely unchanged. Stocking densities may instead be increased by reducing the pen area made available for cattle (i.e. through electric fencing). Dust may still be emitted from the excluded pen areas, although this will be dramatically reduced since cattle hoof action is the main mediator for manure-related dust emissions.

Substitution

Not applicable

Engineering and other physical controls

Engineered controls such as buffer distances provide effective separation distances to reduce dust concentrations to levels suitable for the surrounding community, although emissions themselves are not reduced. Other effective engineered or physical controls include windbreaks, good pen design, bedding materials and water curtains.

Administrative controls

Administrative controls help manage dust suppression efforts. For example, the use of variable stocking densities may require administrative controls to specify the conditions/threshold values required for stocking densities to be increased, or decreased.

Personal protective equipment (PPE)

In addition to generic PPE such as dust masks and eye wear (wrap-around sunglasses), bandannas are worn in the US by feedlot workers (i.e. pen riders) as a specific aid against manure-related dust. Pen riders typically keep bandanas around their necks and use them occasionally over their noses and mouths when dust concentrations are high. The effectiveness of this approach is not believed to have been evaluated in any sophisticated way (Auvermann 2016).

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