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Dust emissions from a beef cattle feedlot on the Darling Downs

Queensland Government
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1 Abstract

Dust is one of the most contentious issues facing intensive livestock operations. On occasion, dust can create unpleasant working environments for feedlot workers and increase cattle mortality rates (Taylor and Stevenson 2003). The introduction of the National Pollutant Inventory (NPI) has resulted in feedlots having to report fine particle emissions (as particulate matter less than 10 μm) if their fuel use (e.g. gas and diesel) or cattle numbers exceed set criteria. The emission rate data for dust with a diameter of less than 10 micron (PM_{10}) that is currently used in Australia is based on previously published American research. Research that is more recent has shown these values to overestimate the actual amount of PM_{10} emitted.

To assess the applicability of the American data for Australian feedlots and to collect baseline data on dust in Australian feedlots, DPI&F developed and implemented a dust-monitoring regime.

Dustfall was collected at 17 sites in and around a Darling Downs feedlot. Such sites were located within feedlot pens, in areas away from the feedlot pens, near roads and in background locations. At the end of each month, the sample collection bottles were replaced with fresh bottles and the samples taken back to DPI&F laboratories in Toowoomba for analysis. Samples were analysed according to AS NZS 3580.10.1-2003 *Methods for sampling and analysis of ambient air - Determination of particulate matter - Deposited matter - Gravimetric method*. Additionally, one week of intensive high volume sampling and real time analysis was undertaken. Co-located high volume samplers were used to measured 24 hour total suspended particulate and particulate matter less than 10 micron concentrations. During this period, real time PM_{10} concentration measurement was undertaken using a DustTrak dust analyser with a 10-minute averaging period.

The results of the dust fall monitoring showed that for a feedlot sited in an agricultural area it was unlikely that nuisance dusts associated with a feedlot would travel far enough to cause nuisance above that already experienced as a result of dust emitted from normal agricultural activities. The organic matter in the captured dust showed that the feedlot sites had higher levels of organic matter than the sites around the feedlot but were not significantly.

The high volume sampling showed that the 24 hour TSP concentrations ranged from 46 ug/m^3 to 349 ug/m^3 with an average of 169 ug/m^3. For PM_{10}, the concentrations ranged from 29 ug/m^3 to 204 ug/m^3 with an average of 100 ug/m^3. Rain fell during the sampling period. PM_{10} concentrations measured using the DustTrak showed that approximately 10mm of rain suppressed the daily average concentrations by around 90% for a period of around 10 hours. In addition, the average PM_{10}-TSP ratio was 59% over the project period. This indicates that the dust in the feedlot has a higher percentage of fine dust than that found in American feedlots.

As the background sites often had higher dustfall than the other project sites it is unlikely that dust from the feedlot would have a significant impact upon surrounding areas. Modelled PM_{10} emission rates for an Australian feedlot and the ratio of fine particulate matter to the total dust concentration (TSP) also indicate that the emission rates developed in American feedlots may not be directly applicable to Australian feedlots. Further research will be required to examine the true emission rate of PM_{10} from Australian feedlots.

2 Executive Summary

Dust in beef cattle feedlots may impact on the health and wellbeing of workers and animals, and community amenity. Unfortunately, there is currently no data available on dust characteristics and emissions from Australian feedlots. The introduction of the NPI handbook for beef cattle feedlots in 1999 and subsequent revision in 2001 (National Pollutant Inventory 2001), resulted in some feedlots reporting emissions of particulate matter less than 10 μm (PM_{10}). Under NPI methodology, emission rates for feedlots are estimated based on American data, however, it has recently been proven that such American data overestimates the actual emissions from American feedlots. Additionally, there is no data on typical dust fall levels for Australian beef cattle feedlots.

A feedlot was selected for collection of Australian data. It was representative of larger Australian feedlots in terms of design and management. The feedlot was located on the Darling Downs in Southern Queensland. The capacity of the feedlot is approximately 15,000 standard cattle units (SCU), making it the eleventh largest feedlot currently operating in Australia. Dust fall was monitored monthly at seventeen sites over a twelve-month period. Additionally, a week of intensive monitoring was undertaken using a pair of co-located total suspended particulate and PM_{10} high volume samplers. Sampling was also undertaken in real time during this period using a DustTrak real time PM_{10} analyser.

Dust fall gauges capture the larger dust particles that are deposited relatively close to their source. These have been shown to be a major cause of complaints (Vallack and Shillito 1998). The data indicated:

- dust fall was greatest near roads in and around the feedlot (average 27.7 g/m^2/month of insoluble solids) followed by;
- the background sites (average 12.5 g/m^2/month of insoluble solids);
- sites within the feedlot (average 9.6 g/m^2/month of insoluble solids); and
- generally, the intermediate sites located on the edges of the feedlot pens area had the lowest dust fall (average 3.2 g/m^2/month of insoluble solids).

This showed that even thought the dust deposition rate in the feedlot pens was high; it was unlikely that the larger particles would be transported over a large distance by local winds.

For the dust fall results, low variability was observed between months. The feedlot and intermediate sites indicated that dust generation from both pens and internal roadways in the feedlot was relatively constant. In contrast, the roadway and background sites showed a large amount of variation between months, indicating that the emission rate of dust near these sites was not constant over time, possibly influenced by factors such as vehicle movements.

The PM_{10}-TSP ratio is used in the literature to define the fraction of total airborne dust that has a particle diameter of less than 10 μm. The published values indicate that 20 to 40% of the total dust in American feedlots is less than 10 μm in diameter. This project has shown that for an Australian feedlot, approximately 60% of the total suspended particulate matter is less than 10 μm. During the high volume sampling rain fell and the results recorded during this period indicated that the rain did not influence the PM_{10}-TSP ratio. Additionally, it was shown that for a single rainfall event where approximately 10mm of rain fell, the PM_{10} concentrations were suppressed for up to 10 hours.

Overall, the results provide an insight into dust emissions in an Australian context. The results show that the current NPI emission rate data may not accurately reflect the “true” emissions of PM_{10} from Australian feedlots. This is based on back calculated emission rates for the feedlot in question and the fact that Australian feedlot dust has a higher proportion of PM_{10} than that

published for American feedlots. Because of this, it is recommended that further research be undertaken, namely: particle size distribution of dust from Australian feedlots, and determination of seasonal PM_{10} emission factors for Australian feedlots.

3 Background

Vallack and Shillito (1998) concluded that dust was the second most important ambient air pollutant, second only to odour. In a 2000 study of feedlot complaints within Queensland, dust rated as one of the top three environmental issues in terms of complaints recorded by Department of Primary Industries and Fisheries (DPI&F) (third behind odour and surface water pollution) (Skerman *et al.,* 2000).

The two main causes of dust in feedlots are cattle movement and vehicular traffic on roadways (Wanjura *et al.,* 2004). Recent studies in the United States (e.g. Wanjura *et al*. (2004) and Sweeten (2004)) have shown that the emission of particulate matter less than 10 μm in diameter (PM_{10}) for roadways can be, on occasion, greater than that emitted from feedlot pens.

Dust is known to affect animal and human health. The impact of dust on health has been well documented. Certain groups (e.g. elderly people and children) can be more susceptible to dust related complaints such as effects on breathing and respiratory systems, cardiovascular disease, alterations to the body's defence systems, damage to lung tissue, carcinogenesis and premature death (USEPA 1996). The human respiratory system can filter particles larger than 10µm in diameter (Lacey *et al.,* 2002), thus, particles smaller than this are most likely responsible for adverse health impacts on humans. Research has also shown that dust can reduce the productivity of crops and longevity of vegetation (USEPA 1996).

There is limited data regarding the impact of dust on animal production systems. A number of studies have shown that dust can cause health impacts on animals (e.g. Schmidt *et al*. (2002), Taylor and Stevenson (2003), USEPA (1996), Kjelgaard (2004) and Aunan and Pan (2004)).

Chirase *et al*. (2001) concluded that there was limited information explaining the effects of dust on the health and productivity of cattle within feedlots. Their work with goats and feedlot dust showed that there was no ill effect on goats when exposed to dust from a cattle feedlot. Studies by the Prairie Swine Centre (1998) and by Jansen and Feddes (1995) also found no relationship between growth rate, lung score and dust concentration for pigs, indicating that dust may not be as serious a concern for animal health as once thought.

Anecdotal evidence has pointed towards increased cattle mortality in feedlots during dusty conditions. Taylor and Stevenson (2003) studied an Australian feedlot and concluded that, for cattle feedlotting, the risk of bovine respiratory disease (BRD) increased during periods of dry and dusty weather. This is particularly important as over 50% of feedlot animal deaths in the United States were attributed to BRD over the 1994 to 1999 period (Ishmael 2001). Data from Australian feedlots showed a similar distribution.

The deposition of dust is a major cause of nuisance complaints (Vallack and Shillito 1998; Skerman *et al.,* 2000). Dust deposition is assessed using dustfall methods that report insoluble solids. Insoluble solids provide an indication of nuisance (Bardsley 2000; Vallack and Shillito 1998). Vallack and Shillito (1998) reviewed a number of deposition standards from around the world relating to insoluble solids. A summary of their review is shown in Table 1. Bardsley (2000) discussed the uses of dust fall gauges for dust monitoring in Australia and listed some typical dust fall values. These are summarised in Table 2.

Table 1: Dustfall air quality criteria as reviewed by Vallack and Shillito (1998)

Country	Comment	mg/m^2/day	g/m^2/month
Argentina	Annual average	333	10.0
Australian (WA)	Loss of amenity first perceived	133	4.0
	Unacceptable reduction in air quality	333	10.0
Canada			
Alberta	Annual average	180	5.4
Manitoba	Annual average	153	4.6
	(maximum acceptable)	266	8.0
	(maximum desirable)	200	6.0
Newfoundland	Annual average	153	4.6
	Monthly average	233	7.0
Ontario	Annual average	170	5.1
	Monthly average	200	6.0
Finland	Annual average	333	10.0
Germany	Long term average	350	10.5
	Short term average	650	19.5
Spain	Annual average	200	6.0
U.S.A			
Kentucky	Annual average	196	5.9
Louisiana	Annual average	262	7.9
Maryland	Annual average	183	5.5
Mississippi	Monthly average (above background)	175	5.3
Montana		196	5.9
New York	Annual average (residential areas)		
	During any 12 months no more than	100	3.0
	5% of 30 day values to exceed and	130	3.9
North Dakota	84% to be below	196	5.9
	3 Monthly average	267	8.0
Pennsylvania	Annual average	500	15.0
Washington	Monthly average	183	5.5
Wyoming	Annual average	170	5.1
	Monthly average		

Table 2: Typical dust fall for various sites (Bardsley 2000)

Site	Insoluble solids (g/m^2/month)
Rural	0.39-1.95
Purely residential	1.2-2.7
Residential with light industry	3-4.8
Heavy industry	6-10.5

The National Pollutant Inventory (NPI) is an Internet database that gives information on the types and amounts of pollutants being emitted to the environment by a range of different industries. The manual, Emission Estimation Technique Manual for Intensive Livestock - Beef Cattle Version 2 was first published in 1999 and a revised version was published in 2001 (National Pollutant Inventory 2001).

The NPI can impact on the feedlot industry as feedlots have to report PM_{10} emissions if the feedlot uses a certain amount of fuel (e.g. diesel, petrol, LPG) or have a certain number of cattle above a designated level. It has been shown that PM_{10} emission rates (based on the historical American data) may be overestimating dust emissions, as newer research is providing lower dust emission rates (e.g. Parnell *et al*. (1999)). A summary of PM_{10} emission data for American feedlots is shown in Table 3.

Table 3: Published PM_{10} emission rates and PM_{10}-TSP ratios for US feedlots

Source	Emission rate (kg PM_{10}/1000hd/day)	% PM_{10} of total dust
USEPA (1985)	31.8	25% (PSD)
Sweeten *et al.* (1998)	6.8	41% (co-located samplers)
Parnell *et al.* (1999)	9.1	45% (PSD)
Parnell *et al.* in Sweeten *et al.* (2004)	6.8 Summer 4.5 Winter	<25% (co-located samplers)
Auvermann *et al.* (2003)	N/A	19% (co-located samplers)
Wanjura et al. (2004)	19 (including roads) 3 (pen only)	25% (co-located samplers)
NPI Version 1 (1999)[1]	32.1	N/A
NPI Version 2 (2001)	47.4	N/A

The data in Table 3 shows emission rates based on particle size distribution or co-located samplers. Simply put, the design of a PM_{10} sampling head for a high volume sampler means that the unit can sample particles bigger than 10μm. The use of particle size distribution refers to evaluating the filters from high volume samplers to determine the proportion of the dust trapped on the filters that is actually 10μm in diameter or smaller.

A downside to the NPI is that feedlots cannot adjust their site-specific emissions based on factors such as the number of roadways on the site or on site dust management procedures. This is

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[1] NPI emission rates are defined as kg PM_{10}/ 1000 SCU/ day where 1 SCU is defined as an animal of 600kg live weight, at the time of turn off from the feedlot (DPI 2000). For the purposes of this report 1000 SCU in Australia is assumed to equate to 1000 head as detailed in the American literature.

important as the data presented in Table 3 shows that on occasion, roadways can be the primary source of dust in feedlots. Thus, site design can help minimise possible PM_{10} emissions.

Recent research has published PM_{10} emission rates that are approximately 40% less than the emission rates used in the NPI. With the introduction of load based licensing in a number of states, the industry may be required to pay for emissions that are unlikely to occur. In addition the NPI data is freely available, thus the public perception of feedlots may be unfairly influenced based on the data reported.

4 Project objectives

The aim of this project was to provide Meat and Livestock Australia (MLA) and the feedlot industry with:

- monthly dust fall data collected at 17 sites within and around a feedlot over a 12 month period;
- the relative proportions of organic matter and mineral soil in the collected dust;
- daily total dust (TSP) and inhalable dust (PM_{10}) concentrations every sixth day over a 1 month period measured using the relevant standards;
- diurnal variations in inhalable dust concentrations in the feedlot over a period of 5 days;
- a comparison between the recorded data to published data and standards; and
- recommendations for further work with respect evaluating dust emissions from feedlots.

5 Methodology

5.1 Feedlot selection

The feedlot selected for this study is considered representative of larger Australian feedlots in terms of design and management. It is located on the Darling Downs in Southern Queensland, which is one of the most intensive areas of beef cattle feedlot development in Australia. The capacity of the feedlot is approximately 15000 standard cattle units (SCU), making it the eleventh largest feedlot currently operating in Australia.

5.2 Sampling sites

5.2.1 Selection

Sampling sites were selected in consultation with the feedlot manager and in accordance with Standards Australia (1987) - Ambient air : Guide for the siting of sampling units. The sites are shown in Figure 1 and were selected as to give an indication of the dust levels in and around the feedlot and the distances travelled by the dust from the feedlot. A typical sampling site within the feedlot is shown in Figure 2.

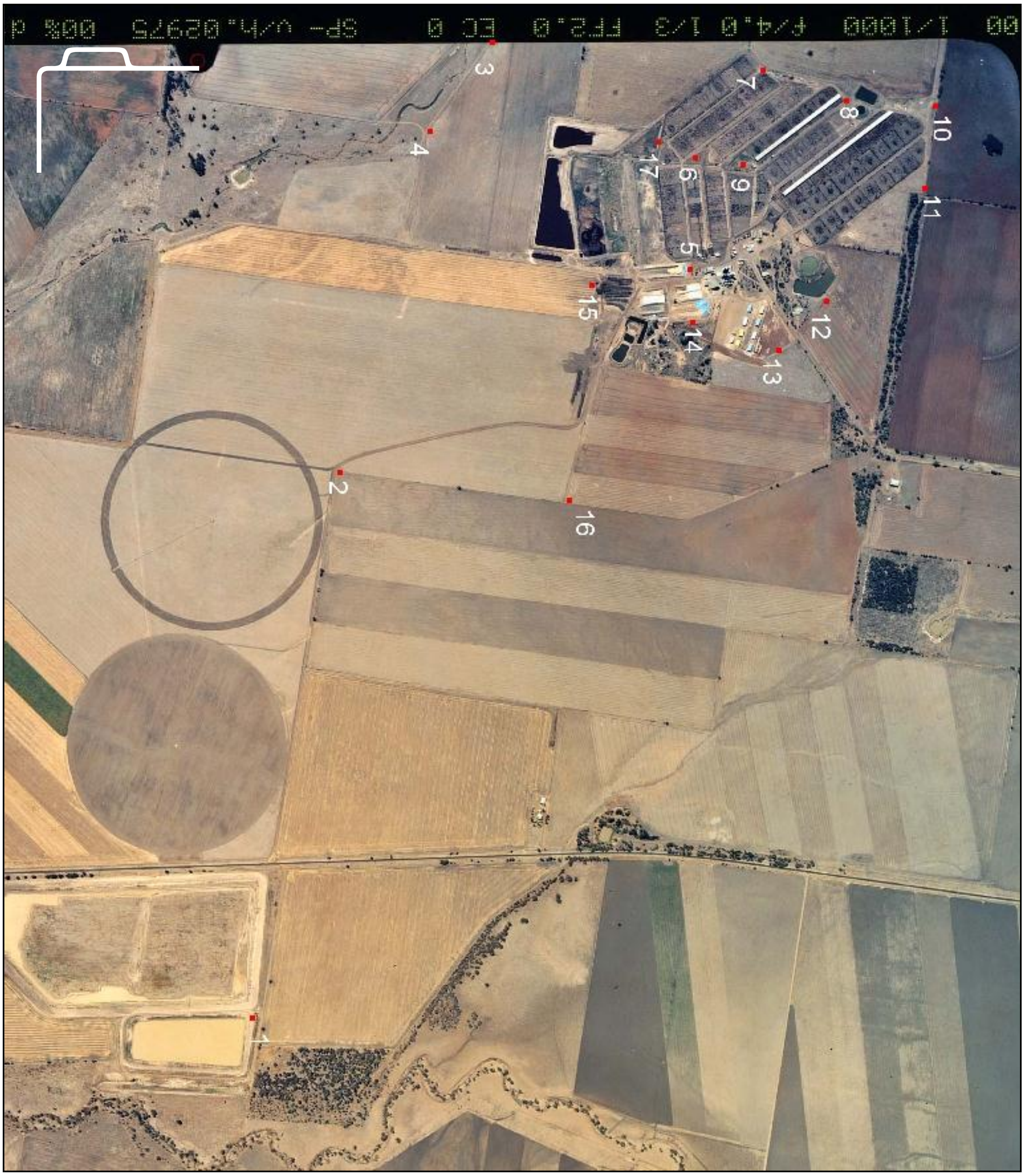

Figure 1: Dust fall sampling site locations.

Figure 2: Sample site 17

5.2.2 Sample site description

Descriptions of the sample sites are provided in Table 4. To enable comparisons of the data, the sites were categorised as follows:

- Feedlot – sites within the feedlot pen area (Sites 5, 6, 7, 8, 9 and 17);
- Intermediate – sites outside of the pen area, but away from major roads (Sites 10, 11, 12, 14 and 15);
- Roadway – sites located near roads on the feedlot site (Sites 2 and 13); and
- Background – sites at least 300m from the feedlot pen area, situated in the surrounding agricultural area (Sites 1, 3, 4 and 16).

Table 4: Sample site descriptions

			Co-ordinates	
Site Number	Description	Category	AMG Easting (m)	AMG Northing (m)
1	Ring tank	D	343380.8	6994908.4
2	Corner A and B Block pens	C	343648.1	6996636.6
3	NW corner of D Block pens	D	344191.5	6998100.5
4	Mid west of D Block pens	D	343922.2	6997703.8
5	D Block lanes	A	344753.4	6997300.5
6	Enclosure at G Block lane	A	344755.8	6997638.5
7	North E Block pens	A	344968.9	6997908.9
8	North H Block pens	A	345239.3	6997814.4
9	Weather station enclosure	A	344912.7	6997642.3
10	NE corner of S Block pens	B	345515.3	6997812.3
11	North Horse 3 pens	B	345486.5	6997599.6
12	Junction West Horse 1 and 2 pens	B	345185.7	6997215.4
13	Horse 4 pen	C	345067.2	6997040.4
14	Grain pad 2	B	344783.8	6997112.5
15	Animal compost area	B	344467.5	6997171.4
16	SW of E Strips cultivation	D	344359.7	6996542.2
17	South E Block pens	A	344669.4	6997678.1

5.3 Dust fall sample collection and analysis

The principle of the method is as follows:

> *Over a given sampling period, particles that settle from the ambient air are collected in a vessel and retained together with any rainwater. The sample is sieved to remove any extraneous matter (>1 mm) and the filtrate containing the deposited matter is quantitatively transferred to a filtration apparatus.*
>
> *The insoluble and soluble materials are separated by filtration and the mass of the dried insoluble solids is gravimetrically determined. From the dried, insoluble solids, the ash and combustible matter are determined. From the filtrate, the soluble solids are determined. The total solids are obtained by the addition of the insoluble solids and the soluble solids. The mass deposition rate of deposited matter is then calculated from the mass of solids obtained and the exposure period. (Standards Australia 2003a)*

Samples were collected on a monthly basis (30 ± 2 days) in accordance with Australian Standard 3508.10.1:2003 (Standards Australia 2003a). Sample bottles were removed from the field at the end of each month, and replaced by a fresh bottle. In accordance with the standard, funnels were cleaned at the end of each sampling period to ensure residual material did not enter the bottle during the following collection period.

Collection was undertaken over a period of 14 months in order to gain a representative 12-month data set. The initial two months of results were discarded due to inconsistencies with the beakers used for analysis. Subsequently, the laboratory methods were refined. In addition, a further two months of data within the 12 month period had to be discarded in accordance with the standard due to high rainfall. After being returned from the field, the following analyses were conducted on each sample.

5.3.1 Determination of total solids

Total solids refers to the mass of the particulate matter deposited in a deposit gauge (Standards Australia 2003a). All matter was removed from the dust fallout gauge through flushing with distilled water and passed through a 1 mm Labtech Essa stainless steel sieve. The matter was then reduced by heating a 2-litre beaker on a SEM 350x650 mm hot plate. The reduced sample matter was then transferred to a pre-weighed 250mL beaker for further evaporation. This was continued until all moisture was removed. Any remaining material was then weighed using a Sartorius BP 3015 electronic balance to four decimal places.

The deposition rate of total solids matter was determined using Equation 1.

$$S_t = \frac{[(m_2 - m_1) - 0.055] \times 10^6 \times 4 \times F}{\pi \times D^2 \times t}$$ **Equation 1**

Where
S_t = mass deposition rate of total solids, in grams per square metre per month
m_2 = mass of the evaporation dish and the total solids in the sample, in grams
m_1 = mass of the evaporating dish, in grams
F = factor to express results to a 30-day month = 30
D = diameter of the funnel, in millimetres
t = sampling period, in days.

5.3.2 Determination of insoluble and soluble solids

Insoluble matter is the mass of the insoluble portion of the deposited matter and soluble matter is the mass of the soluble portion of the deposited matter (Standards Australia 2003a).

The remaining matter from the total solids analysis was redispersed in distilled water. This solution was then passed through a pre-weighed Advantec 47 mm ashless filter using a Buchner funnel. The filter was then dried and weighed.

The deposition rate of insoluble solids matter was calculated using Equation 2.

$$S_i = \frac{(m_4 - m_3) \times 10^6 \times 4 \times F}{\pi \times D^2 \times t}$$ **Equation 2**

Where
S_i = mass deposition rate of insoluble solids, in grams per square metre per month

m_4 = mass of the filter and insoluble solids in the sample, in grams
m_3 = mass of the pre dried filter, in grams
F, D and *t* are as previously defined in Equation 1.

The mass deposition rate of soluble solids was calculated using Equation 3.

$$S_s = S_t - S_i \qquad \textbf{Equation 3}$$

Where
S_s = Soluble solids
S_t = mass deposition rate of total solids, in grams per square metre per month
S_i = mass deposition rate of insoluble solids in grams per square metre per month.

5.3.3 Determination of ash and combustible matter

Ash is the mass of that portion of the insoluble matter remaining after combustion and combustible matter is the mass of that portion that is lost. The filter used in Equation 2 was placed into a pre-weighed crucible and were heated in a West-Carbolite furnace (Type LMF5 ELP) for 30 minutes at 850 °C. The samples were placed in the furnace when it was cold. The total time in the furnace for the ashing process was 2 hours. The weight of sample remaining in the crucible was determined and used in Equation 4 to calculate the mass deposition rate of ash.

$$S_a = \frac{(m_5 - m_3)\times 10^6 \times 4 \times F}{\pi \times D^2 \times t} \qquad \textbf{Equation 4}$$

Where
S_a = mass deposition rate of ash, in grams per square metre per month
m_5 = mass of the crucible and the ash in the sample, in grams
m_3 = mass of the crucible, in grams
F, D and *t* were previously defined in Equation 1.

The combustible matter was then calculated by subtracting the mass deposition rate of ash from the mass deposition rate of insoluble solids (S_i-S_a).

5.4 High volume sampling

Two high volume samplers were used to undertake the sampling, one measuring TSP and one measuring PM_{10}. TSP samplers are used to sample particulate matter that has an equivalent aerodynamic diameter2 (EAD) of less than 50 µm (Standards Australia 2003b). PM_{10} is, by definition, suspended particulate matter with an equivalent aerodynamic diameter of less than 10µm in ambient air (Standards Australia 2003c).

The TSP and PM_{10} high volume samplers were located in the centre of the feedlot (Site 9) with a view to sampling representative dust concentrations. The samplers were located in compliance with AS/NZS 2922-1987.

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[2] EAD is diameter of a spherical particle of density 1000 kg/m^3 which exhibits the same aerodynamic behavior as the particle in question (Standards Australia 2003c)

5.5 Sampling

The details of the samplers used are shown in Table 5. The units were operated according to the relevant standard for TSP (Standards Australia 2003b) and PM_{10} (Standards Australia 2003c).

Table 5: High volume samplers

Brand	Serial number	PM_{10} head	Flow rate calibrated
Lear Siegler	A080	N/A TSP only	August 2004
Lear Siegler	A070	Anderson (#04079)	August 2004

5.6 Total suspended particulates

Prior to sampling, Advantec (203x254mm) glass fibre filters and PALL Gelman Sciences (8x10 inch) Teflon coated filters were weighed under laboratory conditions in accordance with the standard. The non-Teflon coated filters were used for TSP sampling and the Teflon coated filters were used for PM_{10} sampling.

Samples were collected over 24 hour periods for four days. In addition to this, samples were collected over a weekend period (48 hours), as daily filter changes on a weekend were difficult. After each sampling period, the used filter was removed and replaced with an unused filter and the sampler restarted. The used filters were then transported back to the laboratory for analysis.

Prior to weighing, all filters were allowed to equilibrate with laboratory conditions. The volume of air sampled was then calculated using Equation 5.

$$V = \frac{\left(Q_{mi} + Q_{mf}\right) \times t}{2}$$ **Equation 5**

Where
V = volume of air sampled, in cubic metres, corrected to 0 °C and 101.3 kPa
Q_{mi} = initial mass flow rate, in cubic metres per minute, corrected to 0 °C and 101.3 kPa
Q_{mf} = final mass flow rate, in cubic metres per minute, corrected to 0 °C and 101.3 kPa
t = sampling time, in minutes

The TSP concentration for the sampling period was calculated using Equation 6.

$$C = \frac{\left(m_f - m_i\right) \times 10^3}{V}$$ **Equation 6**

Where
C = concentration of TSP, in micrograms per cubic metre
m_i = initial mass of filter, in milligrams
m_f = final mass of filter, in milligrams
V is as defined previously in Equation 5.

5.7 PM_{10}

In accordance with the standard, sample collection and analysis was undertaken with a Lear Siegler high volume sampler in conjunction with an Andersen Instruments Incorporated PM_{10} impactor head. For the collection of PM_{10} samples, Teflon filters (PALL Gelman Sciences 8x10 inch) were used. Each filter was weighed in the laboratory prior to use in accordance with Australian Standard 3580.9.6:2003.

Samples were collected over 24 hour periods for four days and then over a weekend period (of 2 days) due to logistical issues. After each 24-hour period, the used filter was removed and replaced with an unused filter before being transported back to the laboratory for analysis.
All filters were allowed to reach equilibrium for temperature and humidity under laboratory conditions prior to weighing. The volume of air sampled was then calculated using Equation 5. The volume was then incorporated into Equation 6 to calculate a PM_{10} concentration in μg/m^3.

5.8 Real time sampling

Real time sampling was undertaken using a DustTrak 8520 real time sampler (Serial number 23825) between 16 and 19 August 2004. The sampler was located in close proximity to the high volume samplers. Prior to sampling, the unit was cleaned and zeroed in accordance with the DustTrak Operation and Service Manual (TSI incorporated 2003).

The unit was programmed to operate during the same collection period as the high volume samplers with an average concentration recorded every 10 minutes.

The DustTrak monitor is factory calibrated to the respirable fraction of standard ISO 12103-1, A1 test dust (TSI incorporated 2003). To calibrate the unit with respect to feedlot dust, a new calibration factor was calculated. This was achieved using Equation 7.

$$NewCal = \left(\frac{C_{ref}}{C_{DT}} \right) \times C_{cal}$$

Equation 7

Where:
NewCal = new calibration factor
C_{ref} = Average concentration recorded by the PM_{10} reference instrument (μg/m^3)
C_{DT} = Average concentration recorded by the DustTrak (μg/m^3)
C_{cal} = Current calibration factor (factory set to 1).

5.6 Meteorological data collection

5.8.1 General - two metre measurement height

Wind speed and direction data was sourced from a 2-metre weather station located on site. Where data was unavailable, it was supplemented from the Bureau of Meteorology site at nearby Dalby or the SILO database (http://www.bom.gov.au/silo/).

5.8.2 Modelling - ten metre measurement height

Weather data for modelling was sourced from an on site 10m weather station operated by MLA. Scalar averaging was used to calculate hourly wind speed and direction. Relevant averaging procedures were used to calculate hourly temperature, solar radiation and standard deviation of wind direction.

Due to limited data, atmospheric stability classes were calculated using the Sigma-A method (USEPA 2000). This method is turbulence-based and uses the standard deviation of the wind direction in combination with scalar mean wind speed. Describing the method is beyond the scope of this document however, further information about the method can be found in *Meteorological Monitoring Guidance for Regulatory Modelling Applications* (USEPA 2000).

5.9 Back calculation modelling

The aim of the back calculation modelling was to calculate a dust emission rate based on downwind dust concentrations and local meteorology. To calculate an average emission rate from the feedlot using the meteorology and concentration measurements a number of assumptions were made to simplify the modelling process. These included:

- the principal sources of dust in the feedlot were the roadways and pens;
- the emitting surfaces emit uniformly;
- there was no background PM_{10};
- PM_{10} behaves like a gas when dispersing close to the feedlot;
- 1000 SCU = 1000 head;
- the feedlot had a stocking density of 15 m^2 per head;
- standard management practices were in place;
- the measurement point provided a representative dust concentration for the upwind pens; and
- the Sigma-A stability method produced a representative range of stability classes for modelling.

Windtrax version 1 (see Flesch *et al.* (2005) for further information) was used to determine average emission rates. The location and size of the pens and roadways were defined with data taken from a digital dataset supplied by the feedlot. As the dust measurement location was in the centre of the feedlot, only the pens directly upwind of the location were modelled. This was achieved by modelling hourly data points where the wind direction was blowing across the pens in question to the sample location. A screen capture of the model running is shown in Figure 3 with the pens and roadways shown as the darker areas.

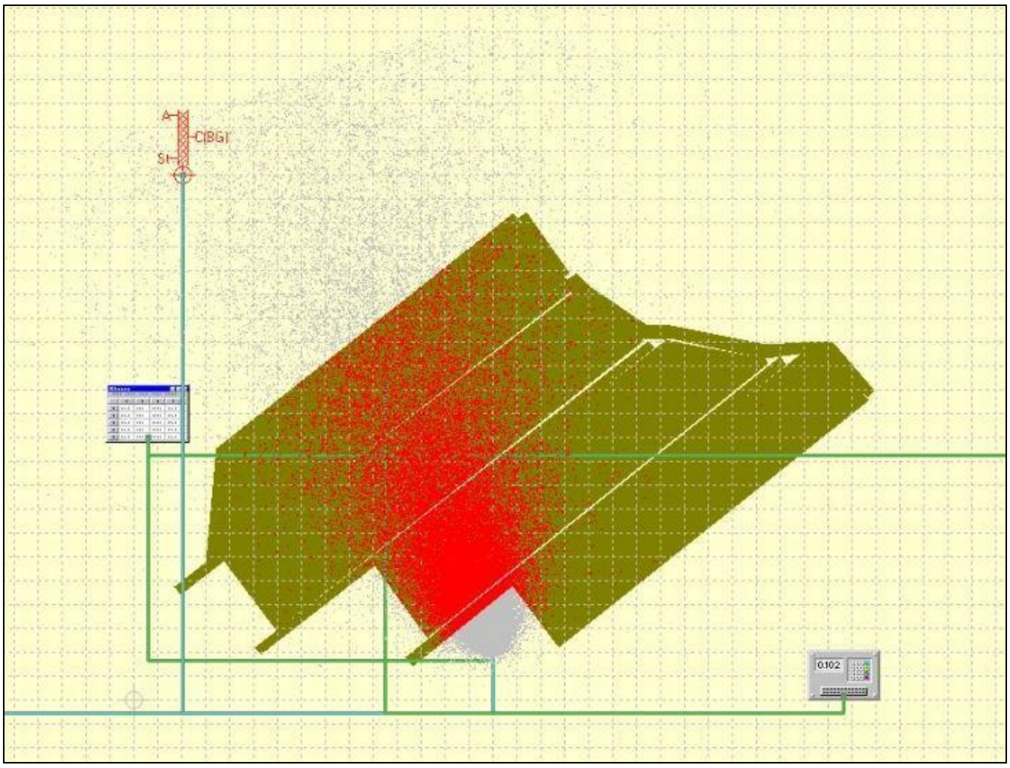

Figure 3: Pens and roadways defined in Windtrax

The inputs required by the model include:

- Surface roughness (m);
- Wind speed (m/s);
- Wind direction (degrees);
- Downwind concentration (µg/m^3);
- Background concentration (µg/m^3);
- Height of measurement (m);
- Pen dimensions (m); and
- Atmospheric stability.

In the absence of in depth meteorological measurements, the surface roughness of the site was defined based upon the 1/10th rule of thumb, in which the roughness height for a site is the height of any obstructions divided by 10. A surface roughness length of 15 cm was used to describe the upwind fetch of the site based on prior experience with back calculation modelling (i.e. Galvin *et al.* (2004) and Galvin and Smith (2005)). Once the modelling is complete the model output provides an emission rate in micrograms per square metre per second. The number of head for the area of the pens was calculated using Equation 8. To enable comparison with the NPI emission data, the amount of PM$_{10}$ emitted per day was calculated using Equation 9.

$$\#Cattle = \frac{PenArea}{STDen} \qquad \text{Equation 8}$$

Where:
Cattle = number of cattle in the pens;
PenArea = area of the pens in m^2; and
STDen = stocking density of the feedlot, 15m^2 per head.

$$ERPM_{10} = \frac{M_{ER} \times A_{TOT}}{1000head} \qquad \text{Equation 9}$$

Where:
$ERPM_{10}$= Feedlot PM$_{10}$ emission rate (kg PM$_{10}$/day/ 1000 head);
M_{ER} = Modelled emission rate (g/day/m^2); and
A_{TOT} = Total area of the feedlot (m^2).

6 Results

6.1 Rainfall

The daily rainfall over the project period is shown in Figure 4. The thick horizontal line in Figure 4 represents mean rainfall for the project period of 59 mm. Figure 5 shows the rainfall by month over the project period. The line in Figure 5 represents the mean rainfall of 59 mm over the project period. The historical mean rainfall (since 1957) for the feedlot from the SILO database is 49 mm thus the season for the project period, had on average, a higher total rainfall than previous years.

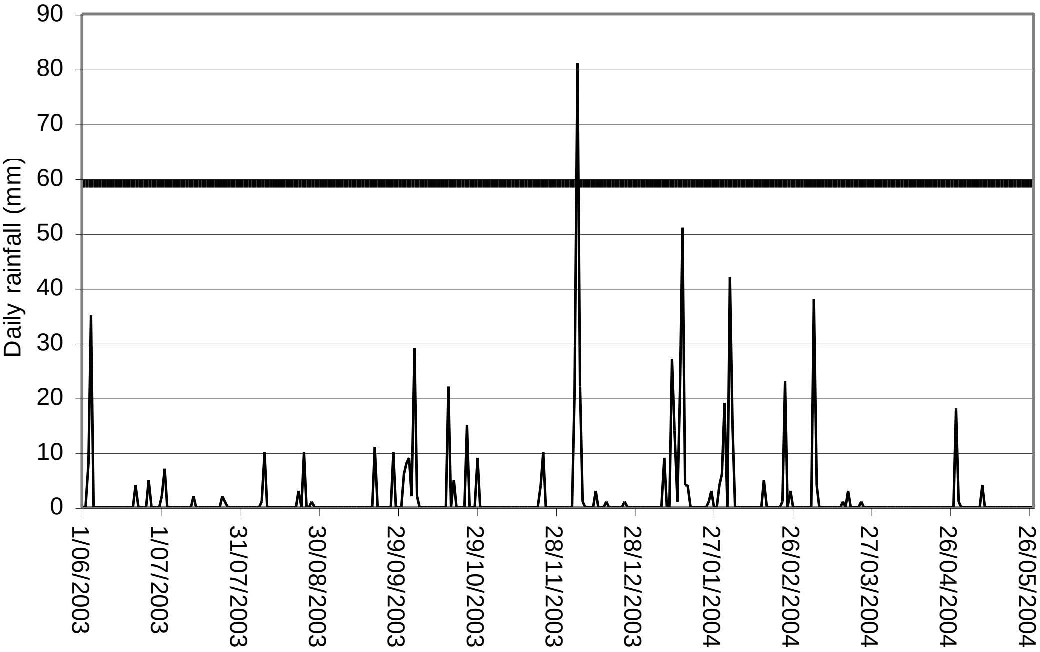

Figure 4: Daily rainfall and mean daily rainfall over project period

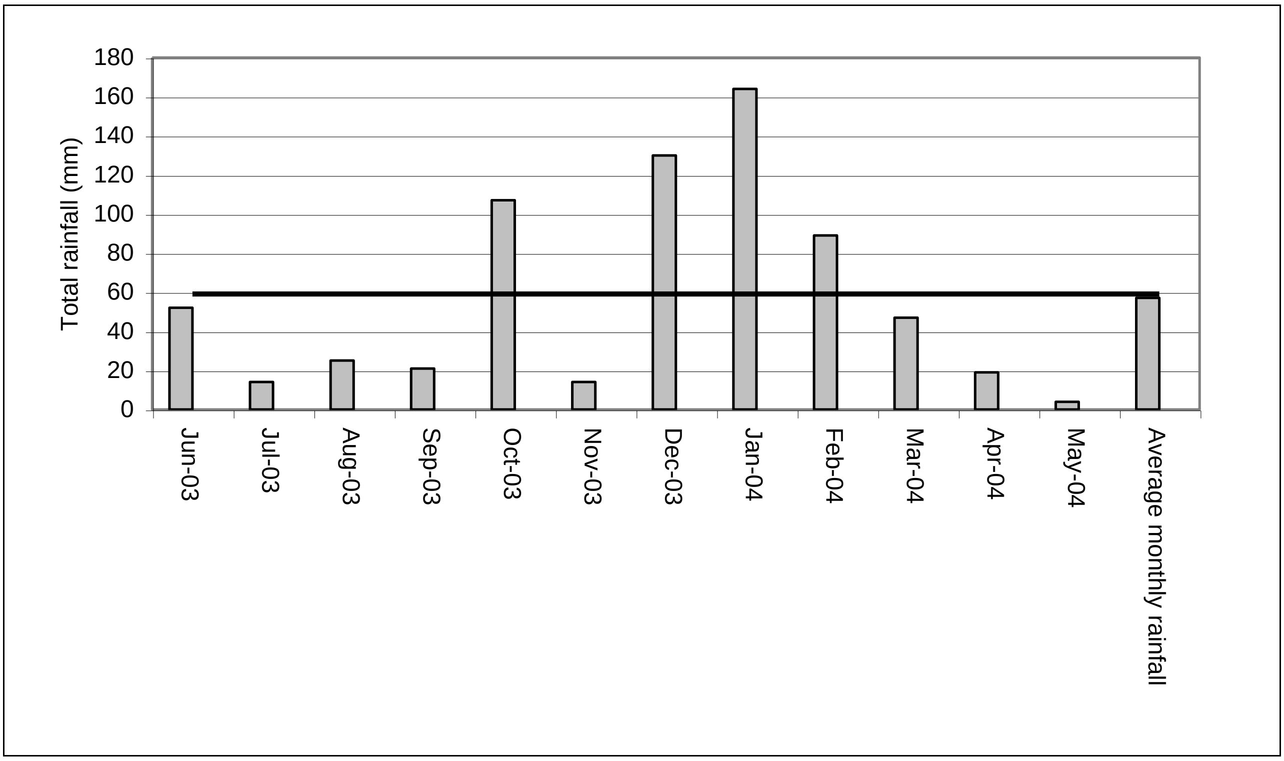

Figure 5: Monthly rainfall over project period

It can be seen in Figure 5 that the months of October 2003, December 2003, January 2004 and February 2004 had above average rainfall. During December 2003 and January 2004 high rainfall caused the fallout gauges to overflow and subsequently, the samples were discarded.

6.2 High volume sampler results

The concentrations determined during the sampling are shown in Table 6 and the PM_{10}-TSP ratio over the sampling period is displayed graphically in Figure 6. A comparison of the Queensland air quality indicators and the levels measured during this project are shown in Table 7.

Table 6: Summary of 24 hour high volume sampling

Date	Rainfall (mm)	PM_{10} (μg/m^3)	TSP (μg/m^3)	%PM_{10} of TSP
16-17 August 2004	0	164	257	64
17-18 August 2004	0	205	349	59
18-19 August 2004[3]	6.2	30	46	64
19-20 August 2004	0	41	73	57
20-22 August 2004	0	60	119	50
Mean	N/A	100	169	59
Mean before rain	N/A	184	303	61
Mean after rain	N/A	51	96	54

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[3] Rain fell during the sample day listed as 18-19 August 2004

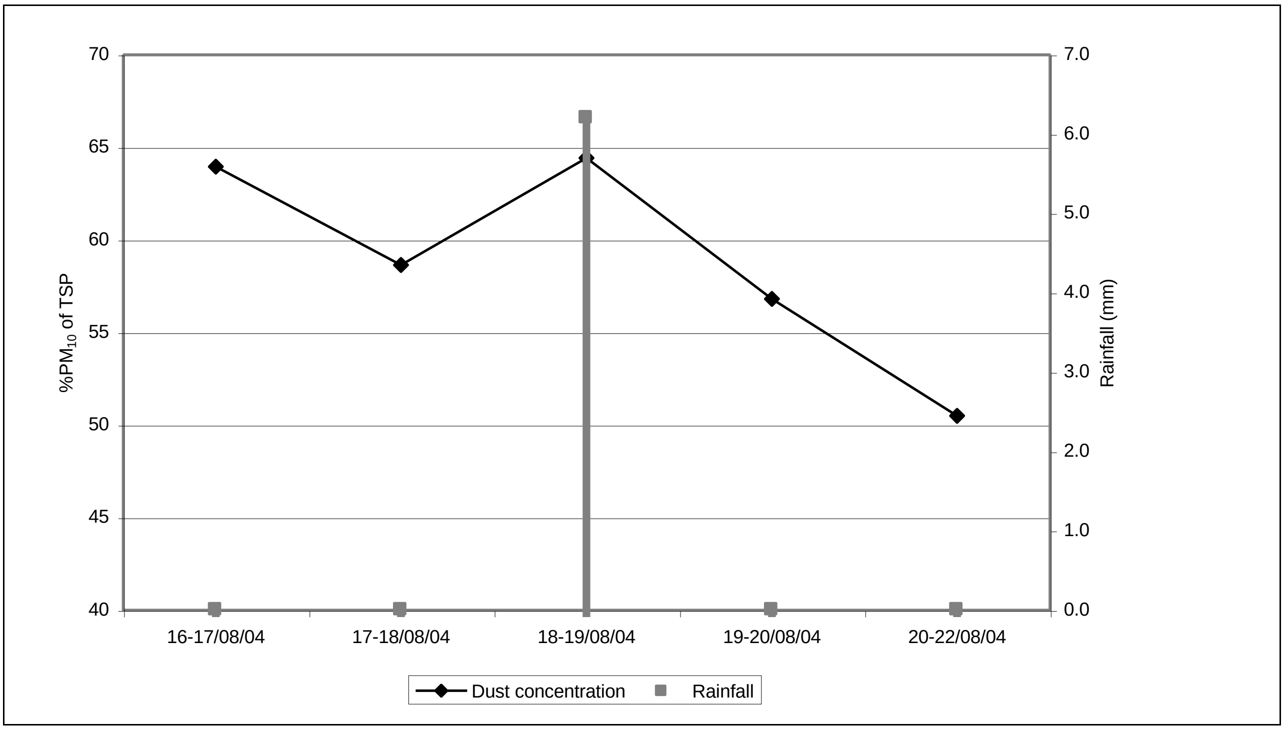

Figure 6: PM_{10}-TSP ratio and rainfall during the high volume sampling period

Figure 6 shows:

- the amount of fine particulate matter in the total dust mass varied with time;
- on average, 59% of dust within a feedlot, by mass, is PM_{10}; and
- after rain fell, the amount of fine particulate matter with respect to total dust decreased.

Table 7: Comparison of high volume sampling and air quality indicators (excluding rainfall events)

Sampling method	Queensland air quality indicator[4] (ug/m^3)	Averaging period	Average measured during this project (ug/m^3)	Averaging period
TSP	90	1 year	303	24 hours
PM_{10}	150	24 hours	184	24 hours
PM_{10}	50	1 year		

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[4] *Environmental Protection (AIR) Policy 1997*, Office of the Queensland Parliamentary Counsel, Queensland

6.3 Real time analysis

The calibration data derived for the DustTrak using feedlot dust is shown in Table 8.

Table 8: DustTrak calibration data

Period	Average DustTrak concentration (μg/m^3)	Average high volume sampler PM_{10} concentration (μg/m^3)	Calculated correction factor	Corrected DustTrak concentration (μg/m^3)
16-17/08/04	24	164	6.8	156
17-18/08/04	33	205	6.2	215
18-19/08/04	12	30	2.5	78

During the sampling period (18-19/08/04) the Bureau of Meteorology weather station and the SILO database indicted that approximately 7 mm of rain fell at and around the site. Based on this, the mean calibration factor for the first two days (no rainfall) was adopted (i.e. *NewCal* = 6.55) to provide a representative dust concentration from the DustTrak. The raw recorded data was adjusted by this calibration factor, thus when comparing the reference method against the DustTrak values for the first two days, the error was approximately 5%. The three hourly rainfall and corrected DustTrak PM_{10} concentrations are shown in Figure 7. As the extreme variability scale for dust concentration over the sampling period made small variations in the dust concentration with time hard to visualise, Figure 7 was replotted using a condensed scale and is shown in Figure 8.

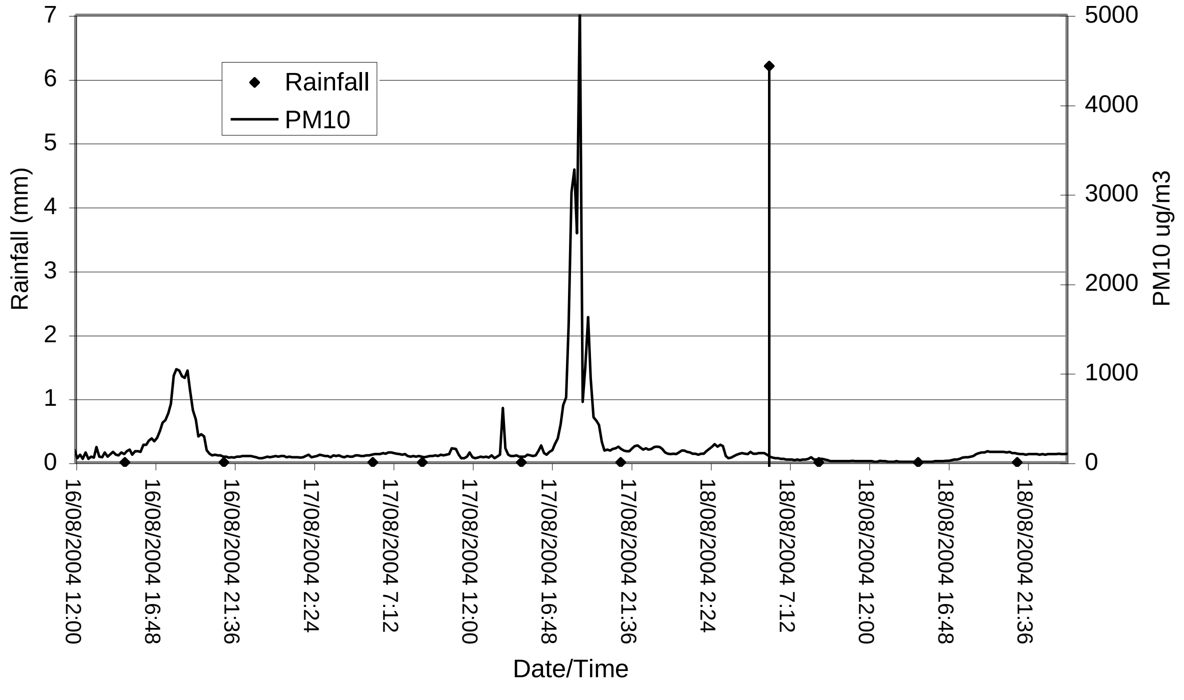

Figure 7: Real time PM_{10} concentrations and rainfall

Figure 7 shows that:

- dust concentrations peaked each afternoon between 5 and 7 pm;
- the average PM_{10} concentration of 165µg/m^3 was similar to the high volume sampler data in Table 8;
- rain fell on the site between 2 and 5am on 18 August; and
- measured dust concentrations were lower after the rainfall.

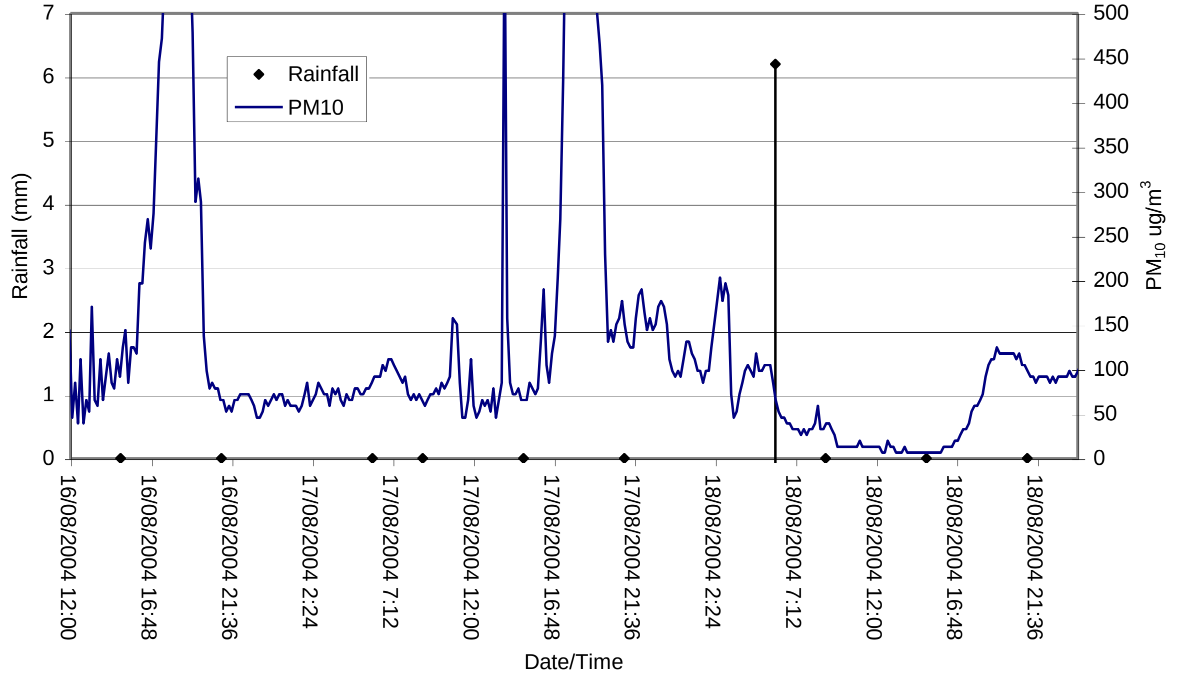

Figure 8: Real time PM_{10} concentrations and rainfall (condensed scale)

Figure 8 shows:

- after the rain fell, dust concentrations were less than those measured on the previous days and remained at these lower levels for approximately 10 hours; and
- the afternoon peak still occurred each day, but not to the extent of the previous days.

6.4 Calculation of PM_{10} emission rates

The results of the back calculation modelling are shown in Table 9

Table 9: Meteorological data and modelled emission rates

Date and time	Wind speed (m/s)	Wind direction (degrees)	Atmospheric stability	Modelled PM_{10} emission (kg PM_{10}/ day/ 1000 head)
17/08/2004 12:00	0.90	327.00	A	18
17/08/2004 13:00	2.10	333.00	A	25
17/08/2004 14:00	2.30	340.00	A	22
17/08/2004 15:00	3.20	328.00	B	52
17/08/2004 16:00	2.90	342.00	B	19
17/08/2004 18:00	2.20	321.00	D	15
17/08/2004 19:00	1.10	356.00	F	24
17/08/2004 20:00	1.40	360.00	F	65
18/08/2004 01:00	3.10	32.00	D	24
Average				29617

6.5 Dust fall

Dust fall gauges provide the user with a variety of analyses, primarily insoluble solids and combustible matter. The insoluble solids fraction is often associated with complaints about dust. Additionally, the percentage of combustible matter can be used to relate the inorganic and organic fractions of the deposited.

Site 15 is not reported in this section due to continual contaminants being deposited in the gauge. The contaminants included things such as bones and rocks. It is thought that crows were perching on the gauges and had deposited the matter in the gauge with the funnels being totally blocked on a number of occasions. An example of the contamination is shown in Figure 9. It can be seen that the sample collected from the feedlot site (site 9) is nearly clear, whereas the sample from site 15 is black.

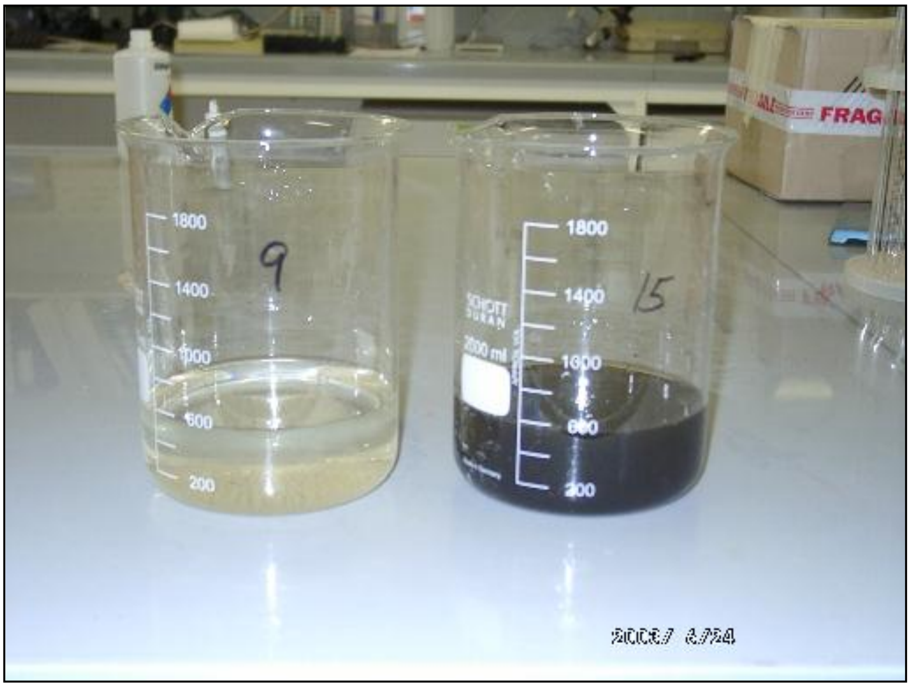

Figure 9: Trapped material from Site 9 (left) and Site 15 (right)

6.5.1 Insoluble solids

The average insoluble solids concentrations for all sites by month and monthly rainfalls over the project period are shown in Figure 10. A linear regression on this data indicated a poor correlation between rainfall and insoluble solids matter (R^2=<0.1) on a monthly basis.

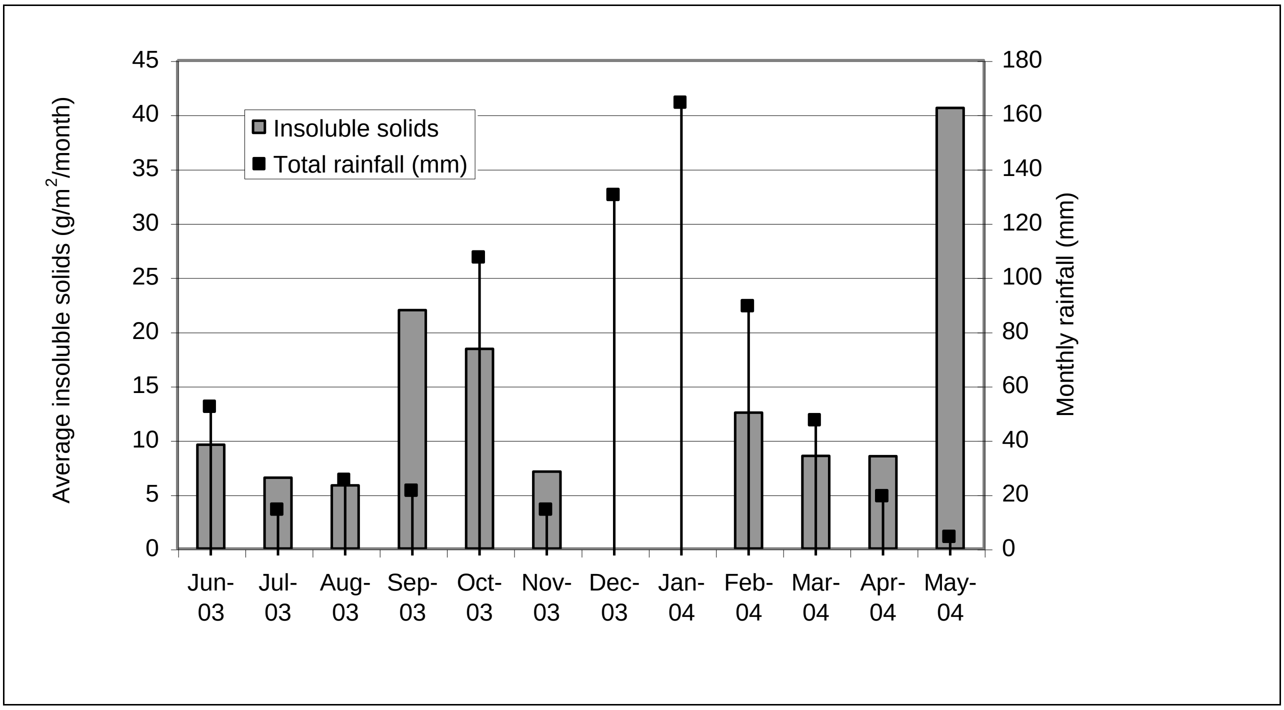

Figure 10: Monthly insoluble solids and monthly rainfall

Figure 10 shows:

- insoluble solids were higher in September 2003, October 2003 and May 2004 than other months;
- there was no obvious correlation between insoluble solids and rainfall; and
- variation in the average insoluble solids deposition by month over the project period.

December 2003 and January 2004 were not analysed due to excessive rainfall during those months, causing the gauges to overflow. The sites and their categories were previously detailed in Table 4. The average monthly fallout data for the grouped sites is shown in Figure 11. Figure 11 shows a very high insoluble solids level for the roadway sites for May 2004. It was found that site 2 had a deposition rate of 0.5 kg/m^2/month. It is unlikely that this was driven by atmospheric or other natural conditions. Therefore, interference with the gauge is likely to have been the cause and the data was subsequently discarded.

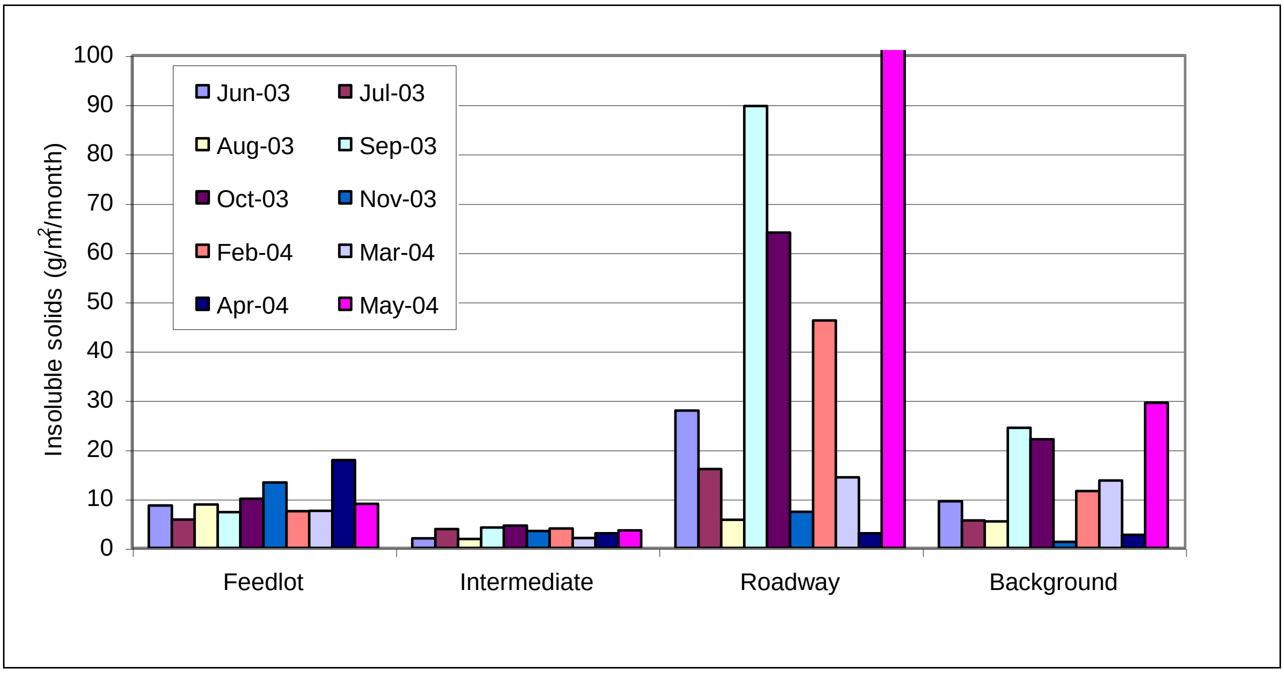

Figure 11: Monthly insoluble solids levels by gauge locality groupings

Figure 11 shows 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.

The dust deposition rate for the grouped sites for the project period is shown in Figure 12. The total bar height is the insoluble solids deposition and the height of the white box shows the amount of combustible matter deposited as a proportion of insoluble solids.

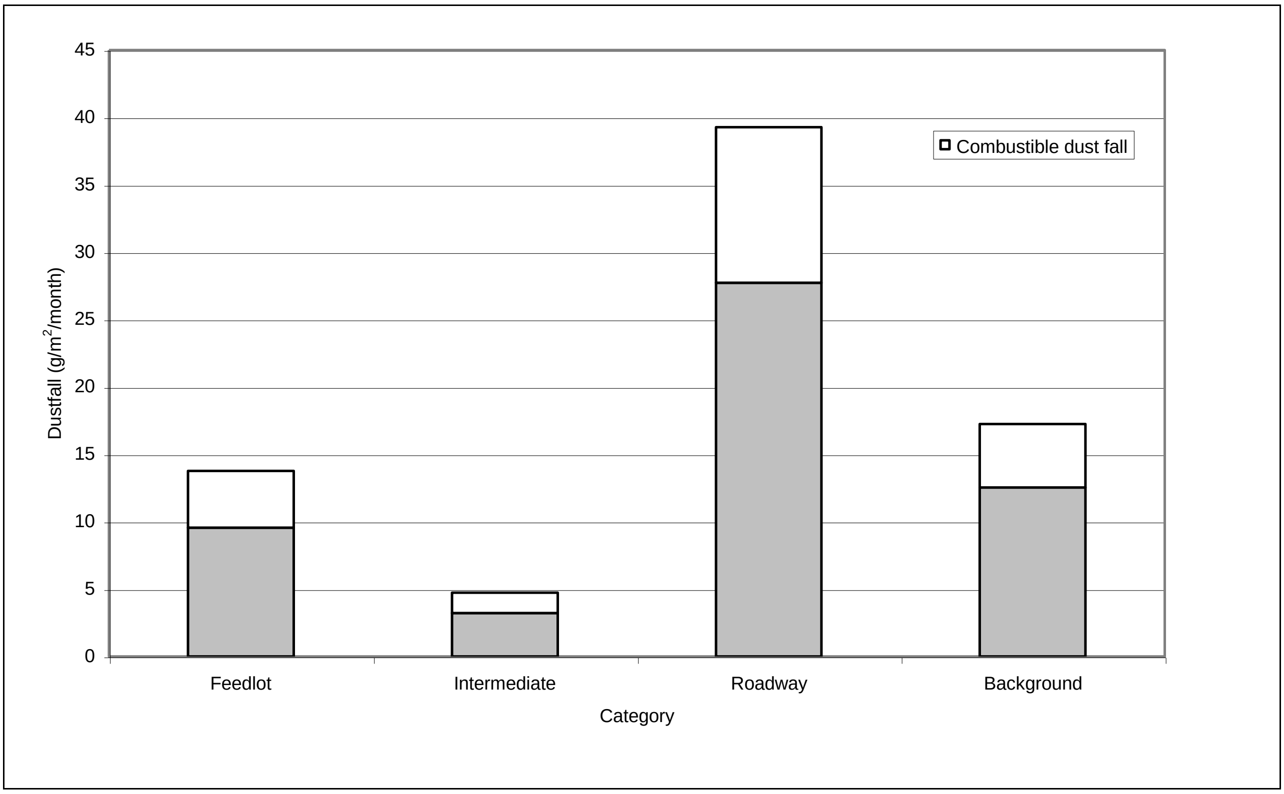

Figure 12: Proportion of combustible matter in dust deposited over the project period

Wind run is often used to relate meteorological data to other information. It is the distance travelled by the wind over the measurement period (i.e. average velocity per hour by number of hours in 1 month) and is a reliable measure of how windy a period was. Wind run was calculated based on the site-specific meteorological data and compared to the insoluble solids levels in Figure 13.

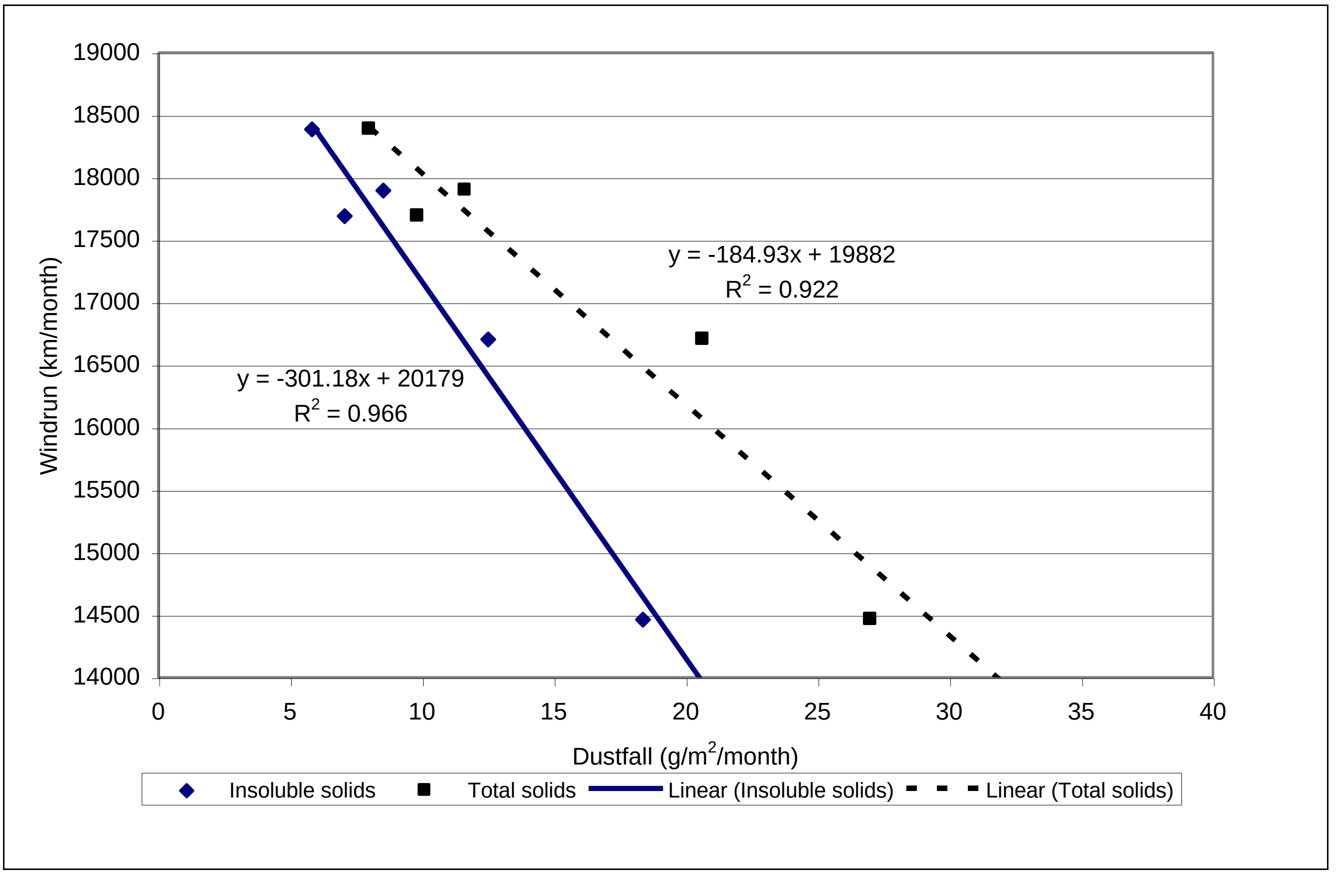

Figure 13: Total and insoluble solids versus wind run for the project

Figure 13 shows that, for all samples on the site over the sampling period, as wind run increased the mean insoluble solids and total solids levels decreased.

To assess all data, an analysis of variance (ANOVA) was performed with the data. As an ANOVA only works on a normally distributed dataset, the data was transformed using $\log_e(x+1)$ to satisfy the assumptions of ANOVA. If a significant difference between months was found, least significant differences (LSDs) were used to further analyse the data. LSDs are based on the t-test and are used to determine significant differences within a significant treatment effect (i.e. months). When a significant group effect (based on the F test) is found the LSD's can be used to compare the levels of the group factor to see if they differ (e.g. testing road, background and intermediate, feedlot).

6.5.1.1 Analysis of months

With the use of the transformation, a significant difference ($p<0.05$) was found based on the grouping between months November 2003, February 2004, March 2004 and April 2004. Differences in other months were not considered significant. Further analysis was undertaken on the significant months and the results are detailed below.

6.5.1.1.1 November 2003

The least significant differences (tested at 5% level of significance) showed that:

- there was a significant difference between the background and intermediate, road and feedlot sites;
- there was a significant difference between the intermediate and feedlot sites; and
- the means show that the dust deposition was greatest at the feedlot sites, followed by road, intermediate and lastly background sites.

The November 2003 insoluble solids for the grouped sites are shown in Figure 14.

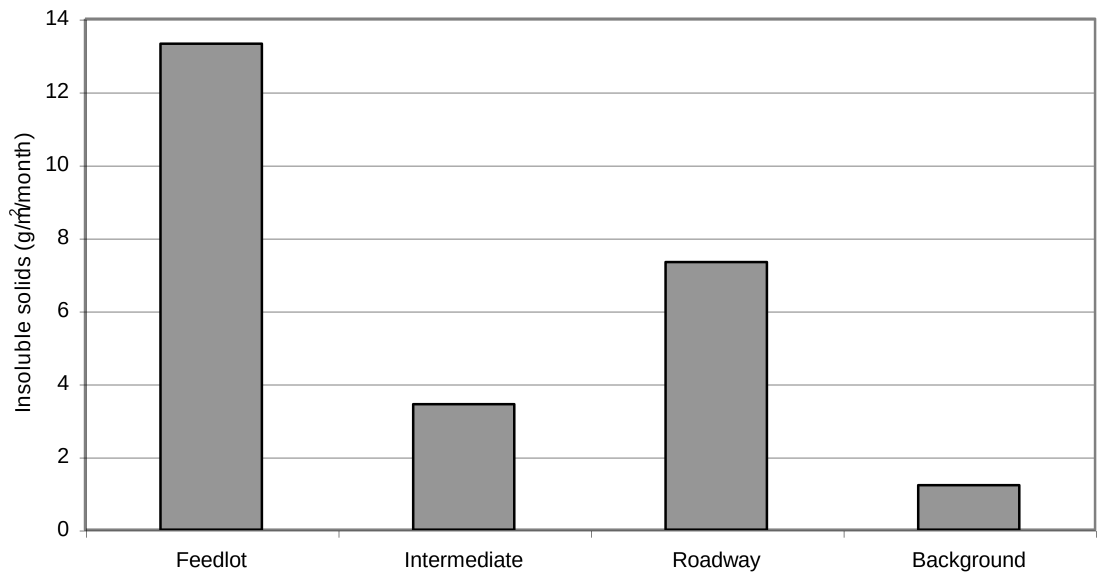

Figure 14: Mean insoluble solids November 2003 by group

6.5.1.1.2 February 2004

The least significant differences (tested at 5% level of significance) showed that:

- there was a significant difference between the road sites and background, feedlot and intermediate sites;
- there was a significant difference between the background sites and the intermediate sites; and
- the means show that the dust deposition was greatest at the road sites, followed by background, feedlot, and lastly intermediate sites.

The average insoluble solids for the grouped sites for February 2004 are shown in Figure 15.

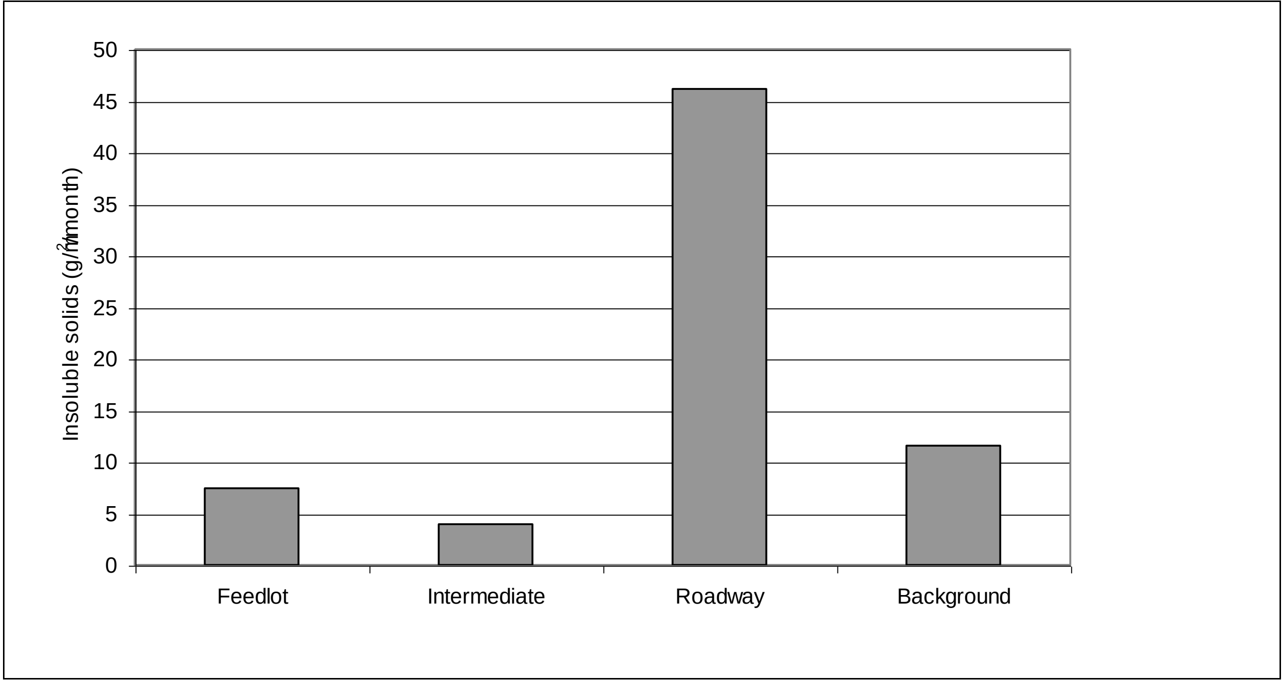

Figure 15: Average insoluble solids February 2004 by group

6.5.1.1.3 March 2004

The least significant differences (tested at 5% level of significance) showed that:

- there was a significant difference between the intermediate sites and the group of road, background and feedlot sites; and
- the means show that the dust deposition was greatest at the road sites, followed by background, feedlot and lastly intermediate sites.

The average insoluble solids for the grouped sites for March 2004 are shown in Figure 16.

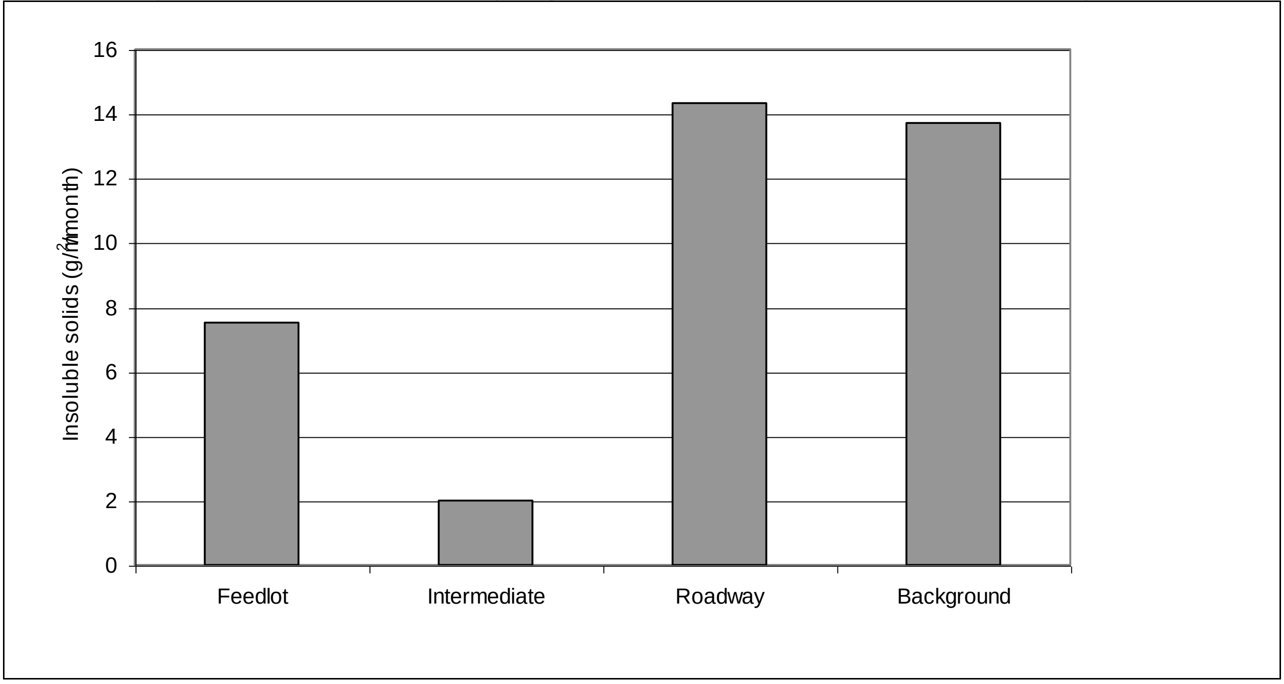

Figure 16: Average insoluble solids March 2004 by group

6.5.1.1.4 April 2004

The least significant differences (tested at 5% level of significance) show that:

- there was a significant difference between the feedlot sites and the group of road, intermediate and background sites; and
- the means show that the dust deposition was greatest at the feedlot sites, followed by road, intermediate and lastly, background sites.

The average insoluble solids for the grouped sites for April 2004 are shown in Figure 17.

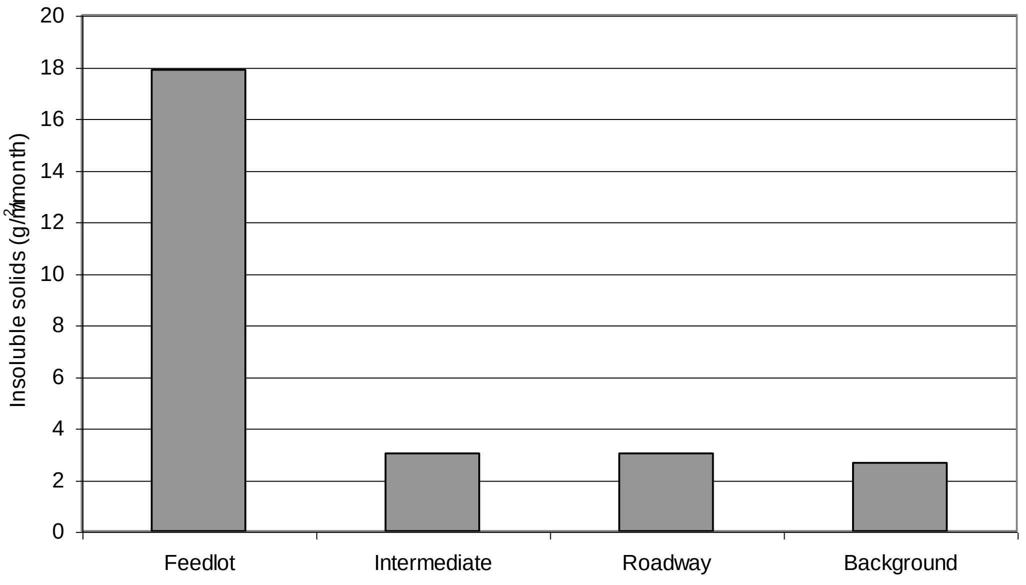

Figure 17: Average insoluble solids April 2004 by group

6.5.1.2 Analysis of grouped sites

The least significant differences (tested at 10% level of significance) for the grouped sites for all months found that:

- there was a significant difference between the intermediate sites and the group of road and feedlot sites; and
- the means show that the dust deposition was greatest at the road sites, followed by the feedlot, background and, lastly, intermediate sites.

The insoluble solids levels for the sites are summarised as a box and whisker plot in Figure 18.

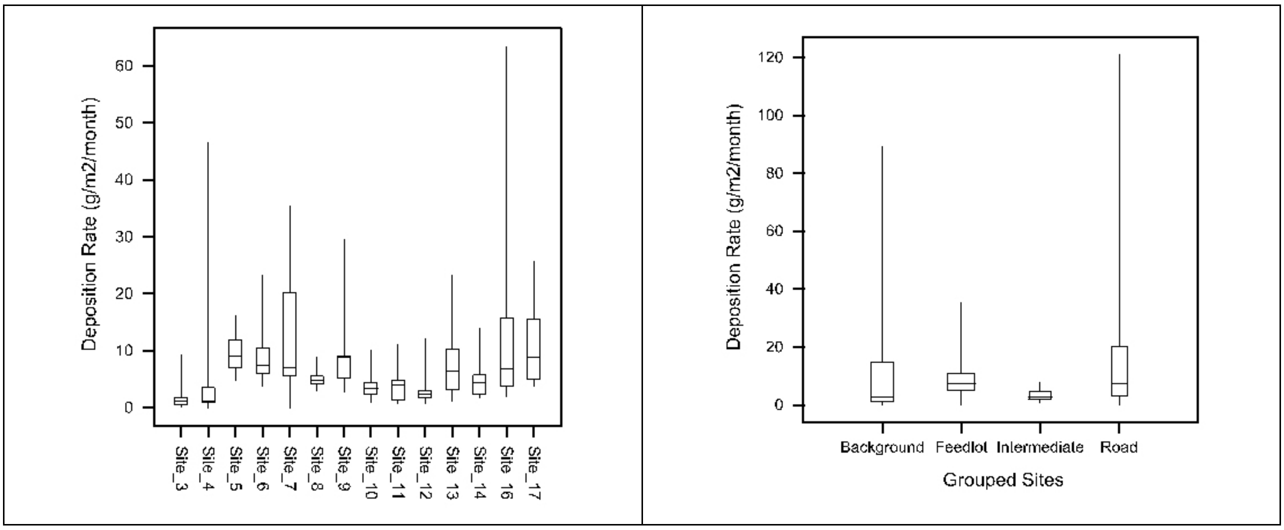

Figure 18: Average insoluble solids by site (left) and by group[5] (right)

The average insoluble solids by site (Figure 18 left) does not contain data for sites 1 and 2 as their average values had large ranges and, thus, large whiskers. When plotted, this resulted in the data for the other sites being too condensed to be viewed.

For average insoluble solids by site, the median value for each sampling event (horizontal line within the box) indicates a number of sites did not have similar values for insoluble solids over time. The low amount of overlap of the boxes indicates that the insoluble solids levels at a number of the sites were different. For the grouped insoluble solids results, the median values vary. In addition, the lack of overlap between the feedlot and intermediate groups shows that the sites were different.

6.5.1.3 Analysis of Individual Sites

When each site was analysed individually, the least significant differences (tested at 5% level of significance) showed that:

- there was a significant difference between site 2 and all other sites; and
- the means show that site 2 is the highest, followed by 1, 7, 5, 6, 17, 16, 9, 13, 8, 14, 11, 10, 4, 12 and lastly 3.

6.5.2 Combustible matter

For this project, combustible matter will be used to examine the amount of manure in the collected dust. The monthly combustible matter for all sites and mean monthly rainfall is compared in Figure 19. The data for December 2003 and January 2004 was discarded due to overflowing fallout gauges, as per the standard.

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[5] Two data points from site 2 (road) were removed as they recorded abnormally high rates of deposition per square meter per month. This was deemed a result of interference with the gauge.

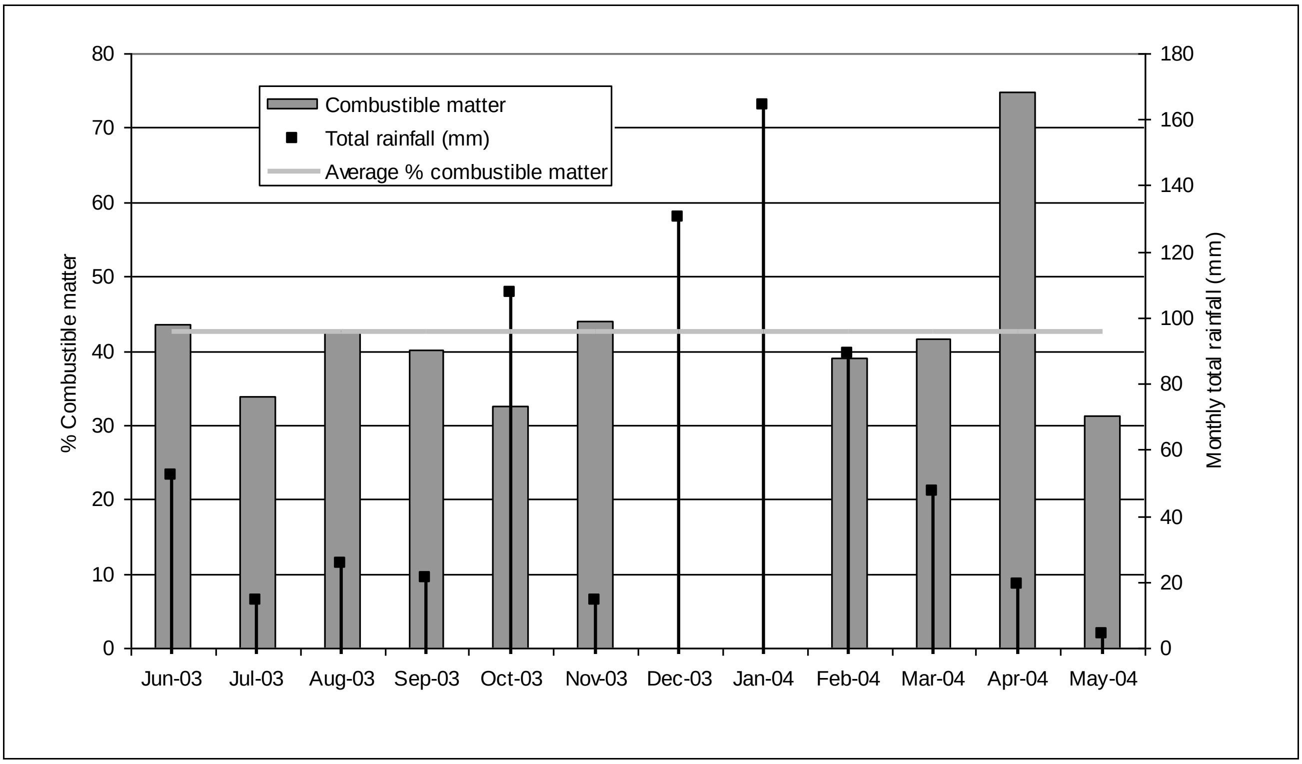

Figure 19: Percentage combustible matter June 2003 to May 2004 for all sites

Figure 19 shows that:

- the proportion of combustible matter, expressed as a percentage of combustible matter in the captured dust remained relatively constant with time;
- the month of April 2004 had a much higher percentage of combustible matter than the other months; and
- visually, there was no apparent relationship between monthly rainfall and the percentage of combustible matter in the dusts in and around the feedlot over the sample months.

For the data in Figure 19, a linear regression showed a poor correlation between monthly rainfall and average monthly percentage combustible matter (R^2=<0.1). The average percentage of combustible matter by site for the project period is shown in Figure 20 and the average percentage of combustible matter for the grouped sites is shown in Figure 21.

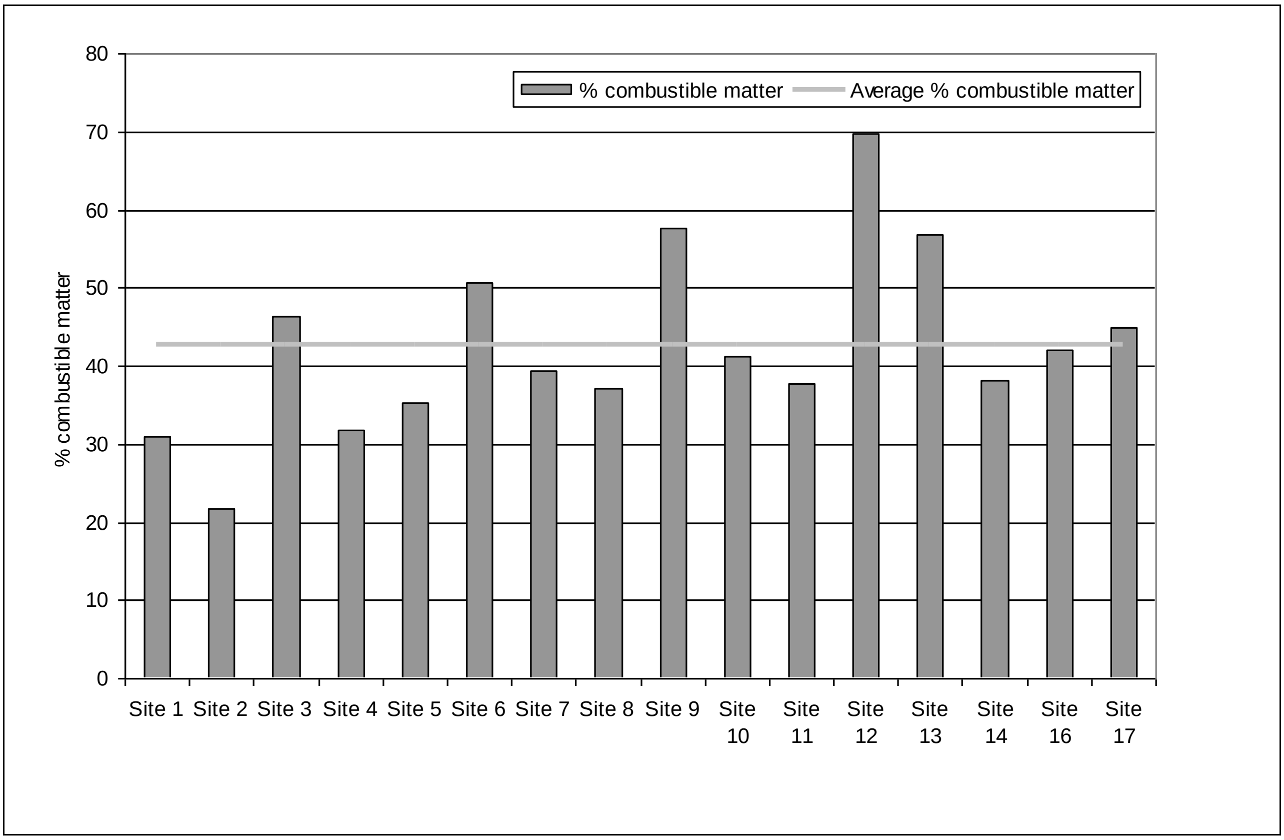

Figure 20: Percentage combustible matter, all sites

Figure 20 shows that:

- site 12 (near the entrance road) had the highest amount of combustible matter in the captured dust; and
- sites 1, 2 and 4 (background sites) had the lowest amount of combustible matter.

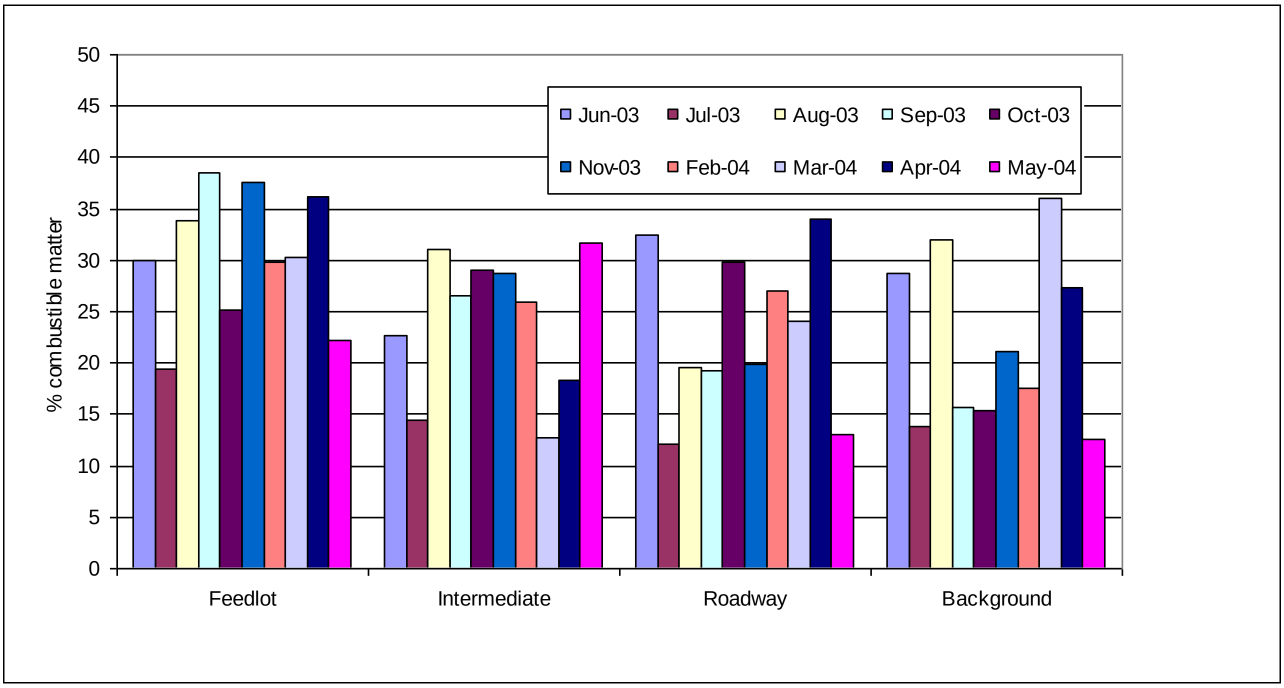

Figure 21: Averaged combustible matter by category for all months

Figure 21 shows that:

- the feedlot sites had the highest percentages of combustible matter followed by the intermediate and then roadway and background sites; and
- the roadway and background sites had higher variability between months than the other categorised sites.

Wind run was calculated based on the site-specific meteorological data and compared to the percent combustible matter levels. This is shown for the months where site-specific meteorological data was available in Figure 22.

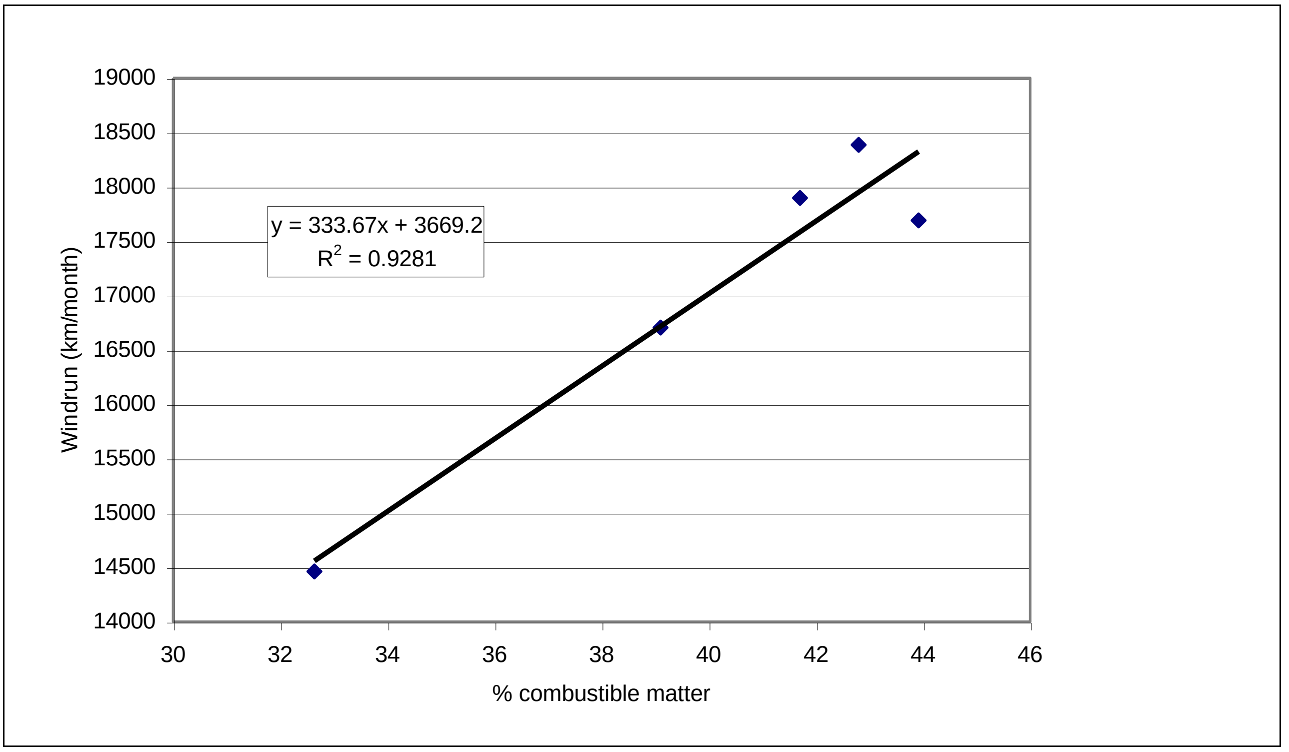

Figure 22: Wind run and percentage of combustible matter for the project

Figure 22 shows that as wind run increased the percentage of combustible matter in the samples increased. An ANOVA was undertaken on all of the data with the analysis examining each month separately and testing whether there was a difference between the grouped sites.

6.5.2.1 Analysis of months

The ANOVA showed that there was a significant ($P<0.05$) group effect (i.e. there was a significant difference between groups) for data for November 2003 and May 2004. For both months, the feedlot and intermediate sites had higher percentages of combustible matter than the roadway and background sites.

The average percent combustibles for the grouped sites for November 2003 are shown in Figure 23 and the average percent combustible matter for the grouped sites for May 2004 is shown in Figure 24.

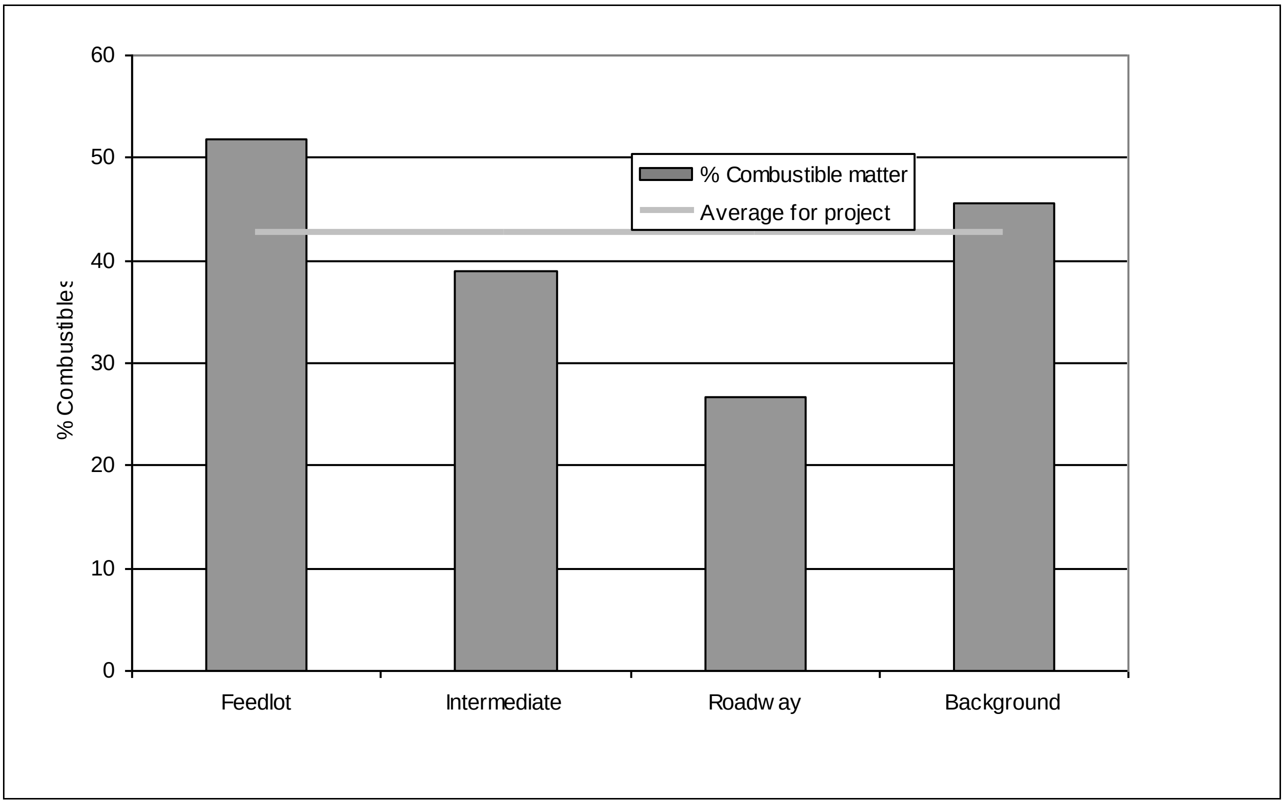

Figure 23: Average percentage of combustible matter, November 2003 by group

6.5.2.1.1

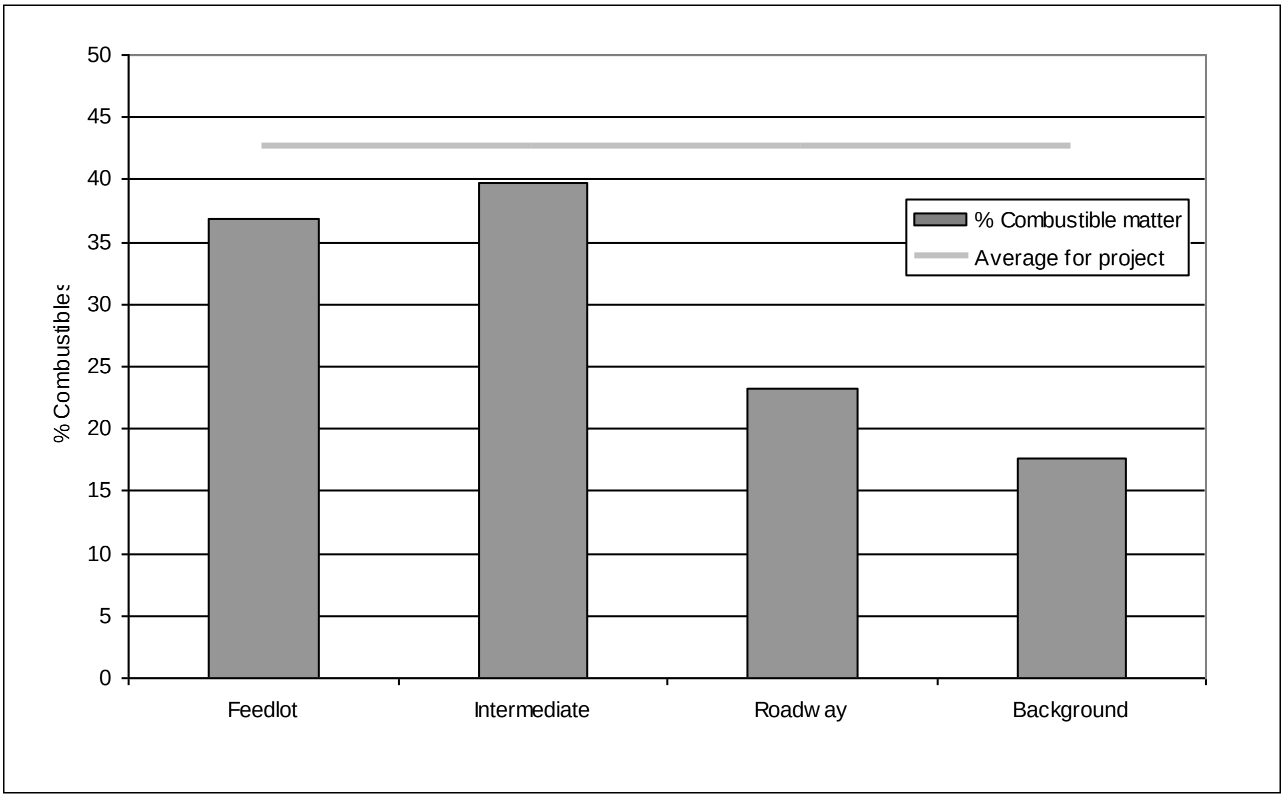

Figure 24: Average percentage of combustible matter, May 2004 by group

6.5.2.2 Analysis of grouped sites

The percentage combustible matter data analysed using the ANOVA is summarised as a box and whisker plot in Figure 25.

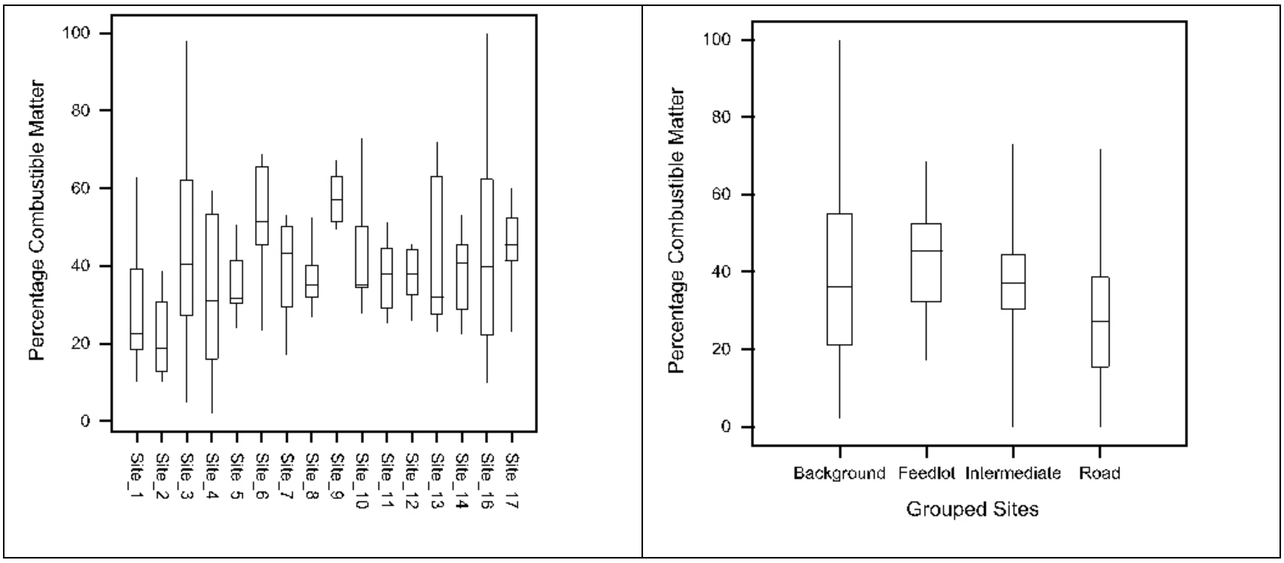

Figure 25: Average percent combustibles for all sites (left) and by category (right)

For all sites, the median value for each sampling event (horizontal line within the box) indicates a number of sites had similar amount of combustible matter in the dust over time. The data also shows that most sites varied over time (distance from median line to top and bottom of box). For box and whisker plots, if the boxes overlap it is unlikely that the samples are significantly different. A number of the boxes overlapped, thus, it is unlikely that a number of the sites were significantly different. For the 12-month period for the grouped sites, all boxes overlapped indicating that a significant difference between the samples and the sites was unlikely.

6.5.2.3 Analysis of Individual Sites

The analysis did not show any significant ($P<0.05$) site effect. However the means showed that site 9 had the largest proportion of combustible matter, followed by sites 6, 3, 13, 17, 16, 10, 12, 7, 14, 11, 8, 5, 4, 1, and lastly site 2 with the lowest proportion of combustible matter.

6.5.3 Relationship between insoluble solids and combustible matter

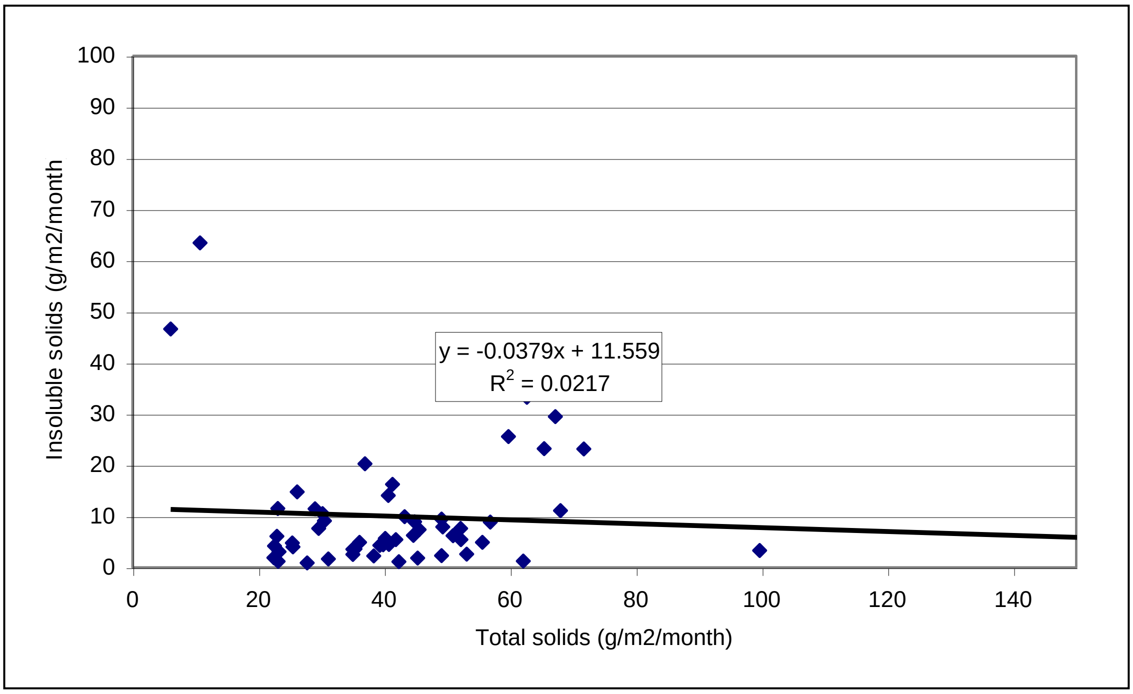

Figure 26: Insoluble solids and combustible matter for all sites all months

The data in Figure 26 shows that there was no relationship (R^2<0.1) between combustible matter and insoluble solids.

7 Discussion

Airborne particulate matter in feedlots can impact upon community amenity and may impact on the health of workers and animals within the feedlot. The emission of dust from feedlots is related to a number of factors, including pad moisture content (Sweeten *et al.,* 1998), surface compaction, manure harvesting, surface water application and ambient meteorological conditions (Auvermann 2003).

The dust emitted from a feedlot contains a range of particle sizes (Sweeten *et al.,* 1998) and these particles can be composed of organic and inorganic fractions. For the purposes of this report, we have classified the particles into three broad ranges:

- the larger particles (greater than 50µm), which usually only remain in the air for a few minutes and settle near the source (measured using dust fall gauges) (QEPA 2004);
- total suspended particulates (<50µm) measured using a high volume; and
- PM_{10} measured using a high volume sampler. Generally, particles less than 10µm can remain suspended and travel long distances. Fine particles (between 0.1-2.5µm) remain in the atmosphere indefinitely and cause a reduction in visibility (QEPA 2004).

In Queensland, air quality indicators (Table 7) are used by the Queensland EPA to indicate the extent to which environmental values may be increased or protected. For TSP, the air quality indicator is 90 µg/m^3 averaged over a period of a year and, for PM_{10} it is 150 µg/m^3 over 24 hours, or 50 µg/m^3 averaged over a year. It is important to note that these are air quality indicators and, while they do not relate directly to health impacts, they are used to indicate the extent air quality is affected as a whole. Generally health impacts are monitored using occupational hygiene methodology and are beyond the scope of this work. All three of these indicators have been measured in this project using the three relevant measurement techniques and are discussed below.

7.1 High volume sampling

7.1.1 TSP

Total suspended particulate sampling captures particles that have an equivalent aerodynamic diameter (EAD) of less than 50 µm (Standards Australia 2003b). The air quality goal for TSP in Queensland is 90 µg/m^3 with an averaging time of a year (OQPC 2004). For American feedlots, Parnell, Lacey, Shaw and Mukhtar in Sweeten *et al.* (2004) reported values of up to 3500 µg/m^3 of TSP in a feedlot with an approximate average of 1200 µg/m^3. In another study, Sweeten *et al.* (1988) measured the net particulate concentrations at three Texas feedlots. The net concentrations are the downwind concentrations adjusted for upwind concentration to reflect the contribution of the feedlot only (Sweeten *et al.,* 1998). They found the net concentration averaged 410 µg/m^3 and ranged from 68 to 882 µg/m^3. Unfortunately, they did not convert these values into dust emission rates or attempt to relate them to the number of animals within the feedlot. Auvermann *et al.* (2003) measured TSP concentrations on the downwind edge of a feedlot and found an average concentration of approximately 800 µg/m^3. The values published by Sweeten *et al.* (1988; 2004) and Auvermann *et al.* (2003) appear to be representative of dust concentrations in American feedlots.

The use of high volume samplers in this project provided an insight into dust concentrations in an Australian feedlot in contrast to a number of American studies, where the study attempted to determine dust emission rates. Exceeding the air quality indicator of 90 µg/m^3 does not necessarily indicate health effects for humans and animals, but a sites amenity may be degraded. The maximum TSP concentration measured during this research was 349 µg/m^3 with an average concentration of 169 µg/m^3. The TSP values, as expected, are greater than the air quality indicator as:

- samples were taken within an emitting source and would not represent ambient concentrations around the feedlot; and
- the data was collected over a very short period of time (a week) and may not reflect longer term trends.

The TSP concentrations measured at the feedlot were lower than those previously recorded at American feedlots. It would be unrealistic to expect the Australian concentrations to match the American concentrations as feedlots cannot be compared with each other without incorporating factors such as climatic differences, stocking density, feed processing methods, feed ration, pen cleaning practices and meteorology.

7.1.2 PM$_{10}$

By definition, PM$_{10}$ is suspended particulate matter with an equivalent aerodynamic diameter (EAD) of less than 10 µm in ambient air (Standards Australia 2003c). However, in practice, PM$_{10}$ impactor heads on high volume samplers are designed to collect particles of EAD 10 ±0.5 µm at a 50% efficiency on a mass basis (Standards Australia 2003c; Wang *et al.,* 2004). This means that up to 50% of particles could be up to 15 µm in diameter. Recently, PM$_{10}$ has become the default air quality standard both environmentally and for health applications. Recently in America, PM$_{2.5}$ has replaced PM$_{10}$ as the air quality indicator. At present, this value has not happened in Australia.

Irrespective of definition, PM$_{10}$ particles have been shown to be responsible for adverse health effects on humans as these particles are small enough to reach the thoracic or lower regions of the respiratory tract (USEPA 1996). Redwine *et al.* (2002) concluded that PM$_{10}$ particles could be inhaled by both humans and animals and lodge in the alveoli. Unfortunately, very little information is available with respect to the influence of specific concentrations and the finer particle sizes on cattle health. For cattle, MacVean *et al.* (1986) found that the incidence of pneumonia in the 16 to 30 days-on-feed group of cattle was closely associated with the concentration of particles 2.0 to 3.3 microns in diameter.

The air quality indicators for PM$_{10}$ in Queensland (and the USA) are 150 µg/m^3 for a 24 hour period, or 50 µg/m^3 over a year (USEPA 1996; OQPC 2004). The 24-hour standard is attained when the expected number of days per calendar year above 150 µg/m^3 is no more than one (USEPA 1996). The 24-hour averaged PM$_{10}$ concentrations on the 16-17th of August 2004 and the 17-18th of August 2004 exceeded 150 µg/m^3.

Whilst the PM$_{10}$ concentrations exceeded the 24-hour standard, it is important to remember that this value is an air quality indicator. Grantham (1992) examined workplace exposure standards (WES) for dusts and showed that different types of dust (not just inorganic and organic fraction) had different exposure levels. A quartz-based dust had a WES of 0.1-0.2 mg/m^3, whereas graphite had a WES of 2.5 mg/m^3. Further research may be required to assess if any health impacts occur in feedlots at the levels observed during this project. The maximum PM$_{10}$ concentration measured during this project was 205 µg/m^3 (0.2 mg/m^3), which was on the lower end of the WES levels in Grantham (1992).

The concentrations measured are indicative of fine particles in a feedlot. Whether or not they are indicative of worst-case concentrations is unknown due to issues such as fluctuations resulting from changes in meteorology, and the makeup of the dust. However, it would be likely that concentrations for a feedlot would be highest on the downwind edge of a feedlot, as at this point, the dust would be a composite of any upwind sources, and that contributed by the feedlot.

The offsite impact of the PM_{10} fraction would be less than that on site, as the dust would become diluted with distance through dispersion. Other typical agricultural sources, such as ploughing and normal wind erosion, would contribute to the total dust load as agricultural lands are known sources of particulate matter less than 100 μm in diameter (Kjelgaard *et al.,* 2004). As the emission of PM_{10} is activity specific for agricultural sources (Gaffney and Yu 2003), it is likely that activities occurring around feedlots can be as significant, if not more significant than the feedlot, as a source of fine particulate matter.

7.2 Real time analysis

7.2.1 Development of DustTrak calibration factor

DustTrak units are was factory calibrated to the respirable fraction of standard ISO 12103-1, A1 test dust prior to purchase. The use of a generic dust for the calibration factor means that errors associated with particle size could occur when using the device. Thus, a specific factor should be developed for use with feedlot dusts. Developing a factor is achieved by comparing the results of the DustTrak unit against a reference method; in this case, the reference method was AS/*NZS 3580.9.6-2003, "Methods for sampling and analysis of ambient air - Determination of suspended particulate matter (PM_{10}) High volume sampler with size-selective inlet - Gravimetric method* ".

Use of the DustTrak and a PM_{10} high volume sampling in the DPI&F workshop prior to fieldwork yielded a calibration factor close to the factory setting of 1, indicating that dust in a commercial engineering workshop may be similar to the ISO A1 test dust. The results in Table 8 showed that the concentrations determined using the DustTrak with the factory standard calibration factor were much less than those determined using the reference method. Experience at the Queensland University of Technology has shown that 3 similar data points can be used to determine a statistically significant calibration factor (Agranovski 2004).

The results in Table 8 showed that for the two days leading up to the rainfall, the calibration factor for the data was 6.9 and 6.2 respectively. On the day the rain fell, the calibration factor was found to be 2.6. Unfortunately, the battery in the DustTrak went flat after this so further data was unavailable.

At low concentrations, it is possible that one big particle may influence the results, thus influencing the calculated calibration factor (Agranovski 2004). This was highlighted where the rain appeared to affect the larger particles, which resulted in a lower total mass and lower difference between the methods (Agranovski 2004). This, however, was not observed in the PM_{10}-TSP ratios, as they did not appear to vary greatly with respect to the rainfall event, which indicated that all particle sizes were influenced to a similar extent by the rain. If the rainfall removed the larger particles more efficiently, the percentage of PM_{10} in the total dust would have increased. For the purposes of this project, the calibration factor for the dry feedlot surfaces was adopted (6.55). This may need to be revisited prior to any future work.

7.2.2 Outcomes from monitoring

In the feedlot, daily PM_{10} concentrations were similar (≤ 200 μg/m^3, Figure 7) during the day and night. A significant increase in concentration occurred late each afternoon (maximum value of ≈5000μg/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 (Parnell *et al.,* 1999; Sweeten *et al.,* 1998). This rise was not evident in the American data shown in Figure 27, as the concentrations increased from 8 pm through to midnight.

During the sampling, on the 18th of August, rain fell in the Dalby area. Following the rain, the measured PM_{10} concentrations decreased for a period of approximately 12 hours. After this time the concentrations rose again to levels similar to those observed prior to the rainfall event. The rain appeared to suppress the previously observed afternoon peak at 7:12pm (Figure 8), as a smaller peak was observed at this time. This affirms the use of targeted water spreading as an effective dust suppression tool.

7.3 PM_{10} –TSP ratio

The ratio of total dust to inhalable dust (PM_{10}-TSP) is commonly recorded in research literature. It is used to define the finer component of the total dust concentration. A number of research projects have outlined PM_{10}-TSP ratios. In these projects, there have been two approaches to determining the PM_{10}-TSP ratio. The first is based on mass, which relates to determining the percentage of PM_{10} in TSP by siting samplers side-by-side (e.g. Auvermann *et al*. (2003)). The other approach has been to co-locate samplers side by side, and, in addition to these measurements determine the particle size distribution using a Coulter Counter (e.g. Sweeten *et al*. (1998) and Capareda *et al*. (2004)).

The Coulter Counter technique provides data on the actual fraction of dust that is below 10 μm. Sweeten *et al*. (1998) concluded that the Coulter Counter method can be used to determine particle size distributions (PSD) for feedlot dust and to supplement direct data collection using PM_{10} samplers. Sweeten *et al*. (1998) found, using a Coulter Counter, their TSP and PM_{10} high volume samplers trapped particles with a mass median diameter (MMD) of 9.5 ± 1.5 μm (AED) and 6.9 ± 0.8 μm (AED), respectively. They concluded that the PM_{10} sampling heads they used were over sampling large particles as, "in theory, a PM_{10} sampler should be able to provide a sample with 100% of particles smaller than 10μm". This is actually incorrect as PM_{10} size-selective inlets are designed to collect particles with an EAD 10 ±0.5 μm at a 50% efficiency on a mass basis. Thus, it would be expected that 50% of particles would be greater than 10 μm up to a size of approximately 15 μm.

Recently, Wang *et al*. (2004) and Capareda *et al*. (2004) examined methods for correcting high volume PM_{10} concentrations to account for the 50% efficiency of impactor heads. The over sampling using PM_{10} heads has lead researchers to believe that, based on a MMD of higher than 20 μm, the PM_{10}-TSP ratio can be less than 15% (Pers comm., Parnell). Wang *et al*. (2004) concluded that the only way to achieve the "real" PM_{10}-TSP ratio was to correct the high volume sampler values with "correct" PM_{10} values based on particle size distribution with respect to PM_{10} concentrations, where all particles are at or below 10 μm. The advantage of this method is that when you are reporting PM_{10} concentrations or, more importantly emissions, you are reporting the actual dust emission rate for particles at or below 10 μm.

For this project, the high volume sampling showed that on average, 59% of the dust from the feedlot is PM_{10} by mass. The value of 59% is higher than the values in Table 3 and, even if corrections were made with respect to PSD, it is likely that the PM_{10}-TSP ratio would still be higher than the published American data.

Given that the NPI data is based on American data with a PM_{10}-TSP ratio of 25%, the Australian PM_{10}-TSP ratio indicates that increasing the emission estimate value in the NPI emissions may be appropriate. However, it is more than likely that the American emission rate data does not adequately reflect emissions at Australian feedlots due to differences in the particle size distribution of the dust, climate and management factors.

The ratio determined in this project did not appear to be influenced by rainfall (Figure 6). It would be expected that larger particles would be removed from the air more rapidly than the smaller particles by rain as the larger particles would be more likely to be impacted upon by the rain and removed from the air. The results show that the ratio remained relatively constant with time. A slight decrease with respect to the mass of PM_{10} in the air can be seen after the rain, but further sampling would be required to confirm if this was a significant effect.

In their study of feedlot dusts, Parnell, Lacey, Shaw and Mukhtar in Sweeten *et al*. (2004), measured TSP and PM_{10} concentrations with co-located samplers before and after a rainfall event. The results of their work, as detailed in Sweeten *et al*. (2004), is shown below in Figure 27. Unfortunately, no data was available on the amount of rain that fell. It should be noted that Parnell *et al*. had a much larger budget and, therefore data set, than that for this project.

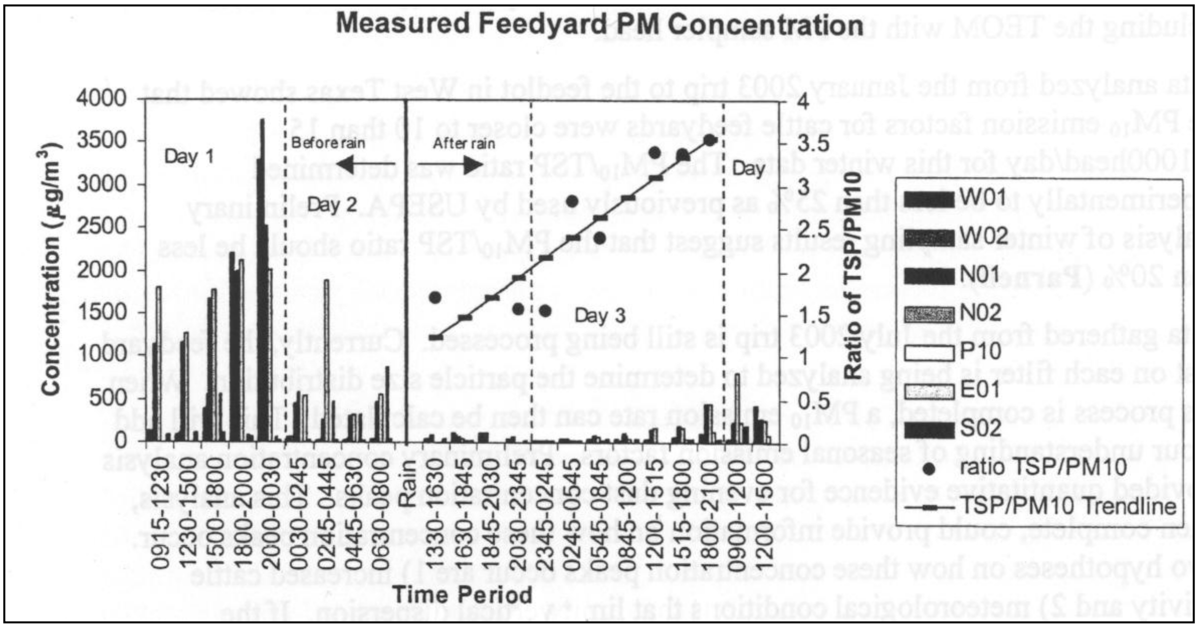

Figure 27: Relationship between rainfall and ambient dust concentration (Parnell, Lacey, Shaw and Mukhtar in Sweeten *et al.* (2004))

Figure 27 shows:

- concentrations varied over the seven sites with respect to time, leading up to the rainfall;
- dust concentrations were reduced by the rainfall event;
- dust concentrations rose approximately 24 hours after the rainfall event; and
- the amount of PM_{10} in the total dust levels changed from 50% of TSP being PM_{10} 3 hours after the rain to approximately 30% 36 hours later.

When Parnell *et al.* sampled every 3-4 hours with high volume samplers, they found that the percentage of PM_{10} in the TSP concentration decreased with time after rainfall. This short-term sampling enabled them to observe trends over a 36-hour period. Parnell *et al.* also found that the total dust levels were reduced after the rainfall event, however, they noted that approximately 24 hours after the rainfall event, concentrations began to slowly increase. This phenomenon was also observed in this study (Figure 8).

Parnell *et al.* used much shorter measurement times than this project (this project used the standard 24 hour periods); hence, they had a much better chance of observing trends with respect to changes in the ratio. However, from the data collected in this project, no rapid change in the ratio within the sampling period was evident.

7.4 PM_{10} emission rates

7.4.1 Background

Recent research such as that summarised in Table 3 support the notion that the USEPA data can result in over prediction of PM_{10} emissions from feedlots. The USEPA is currently waiting on the outcomes of further research before updating its AP42 emission factors for cattle feedlots (USEPA 2005).

The emission of PM_{10} from beef cattle feedlots is a function of seasonal variations in climate, stocking rates, feedlot management practices and extreme weather events (Parnell *et al.,* 1999). The aim of the high volume sampling in this project was to investigate the relationship between PM_{10} and TSP for an Australian feedlot. Thus, the measurement location was in the middle of the feedlot. As this site was not in an ideal location for back calculation modelling only upwind pens were included in the modelling.

7.4.2 Windtrax model

Windtrax version 1 (see Flesch *et al.* (2005)) was used to determine average emission rates. The model is a backward-time Lagrangian stochastic (BLS) dispersion model that calculates emission rates of gas or particulates from a source area based on measured wind speed and gas concentrations downwind of a source. A hypothetical area source is shown in Figure 28.

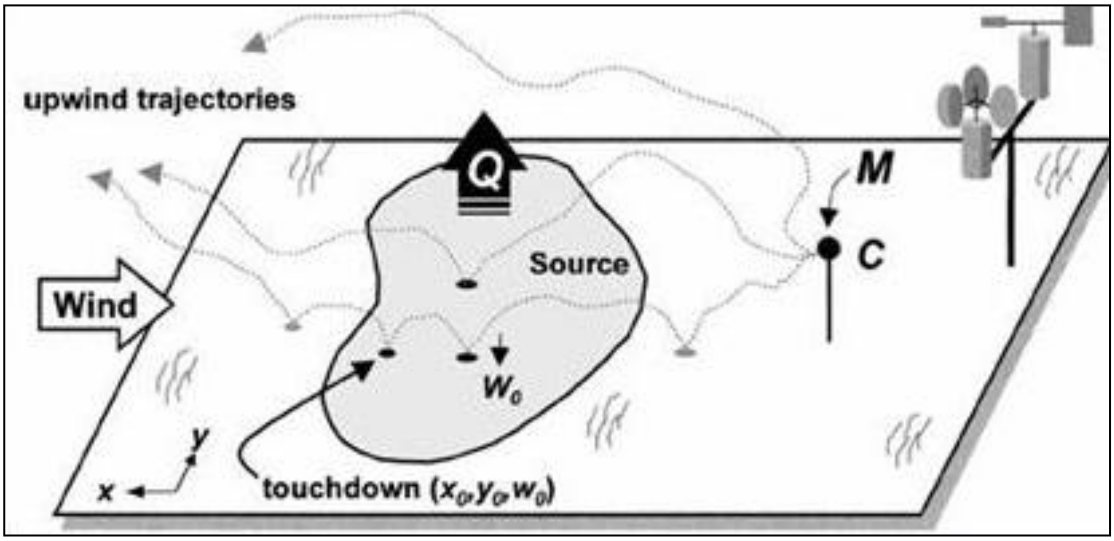

Figure 28: Theory for Windtrax model (Flesch *et al.,* 2005)

Figure 28 shows that concentration above background (C) is measured at point M. The trajectories are calculated upwind of M and the concentration ratio is given by the trajectory touchdowns inside the source. The approach of using backward dispersion modelling has been previously used to develop particulate emission rates for feedlots (eg. Parnell *et al.* (1993; 1999) and Sweeten *et al.* (2004)).

7.4.3 Sources of dust within the feedlot

To undertake modelling of a feedlot, the emitting sources must be identified. One of the assumptions used was that the major sources of dust were pens and roadways. This assumption was based on the findings of Wanjura *et al.* (2004) and Razote *et al.* (2004). Whilst Wanjura *et al.* (2004) found that emission rates from roadways were higher than that for pens, for this project the pens and feedlot were modelled as to have identical emission rates. Figure 3 showed the

Windtrax model with the feedlot emitting sources shown as olive sections. As the major sources of dust within the feedlot are known, other areas within the feedlot such as grassed areas were assumed to emit no dust. The NPI uses an emission rate on a 1000 head basis. This means that fugitive sources such as roads should be included in the back calculation exercise. Therefore combining the pens and roadways is a suitable technique.

7.4.4 Background PM_{10} concentrations

Published studies have shown that harvesting (Ashbaugh *et al.,* 1996) and wind borne erosion (Kjelgaard *et al.,* 2004) are two probable sources of dust within agricultural areas. If background concentrations were available, a modeller (or the model) can subtract the background concentration from the measured downwind concentration. Background PM_{10} concentrations were not measured thus they have not been incorporated in the resultant emission rates. If available, the model would calculate a lower emission rate as the background concentration would be subtracted from the measured concentration. Thus, the emission rates detailed in Table 9 are likely to be maximum emission rates for the sampling period.

7.4.5 Receptor providing an average emission rate

The difference between this work and other back calculation studies such as Galvin *et al.* (2004) , Koppolu *et al.* (2002), Sarkar and Hobbs (2003) and Sommer *et al.* (2004) is that the samples in this study were taken within the source. To overcome the sample location being within the source (as shown in Figure 3), the area sources (pens and roads) defined in the model were only those upwind of the source. This technique ensured that the receptors provided a representative emission rate.

7.4.6 Atmospheric stability

Atmospheric stability is used to represent the inclination of the atmosphere to withstand or increase vertical movement of an odour. Due to a lack of certain meteorological data, Turners and the SRDT methods were not suitable for determination of atmospheric stability and the Sigma-A (σ_A) stability method was used.

The Sigma-A method is one of the methods listed in the USEPA publication, *Meteorological Monitoring Guidance for Regulatory Modelling Applications.* Due to its widespread use, Turner's method is seen as the best procedure for determining P-G stability (USEPA 2000) . Numerous studies have concluded that the different methods provide different estimations of stability class (Bowen *et al.,* 1983; Mohan and Siddiqui 1998; Tripp *et al.,* 2004). Of the published literature, very few researchers have used the Sigma-A method. Current work being undertaken by DPI&F at Clifton on the Darling Downs has shown that of 2500 hours, 68% of time the SRDT and Sigma-A method predicted the same stability class. Of the other 30% of predicted classes at Clifton, half of these predicted more stable conditions and half predicted unstable conditions.

For modelling gaseous compounds, it has been shown that varying stability class by one in either direction about class B, changes the back calculated emission rate. The more stable the atmosphere the lower the predicted emission rate (Galvin 2005). Conversely, the less stable the atmosphere, the greater the predicted emission rate. Experience has shown that under stable conditions, the SRDT and Sigma-A methods had the greatest divergence. Of the nine hours of data modelled, two were under stable conditions. Thus, in this instance the Sigma-A method is likely to have provided a representative estimation of stability classes and therefore PM_{10} emission rate.

7.4.7 PM_{10} behaves like a gas

Whilst not stated explicitly, previous projects investigating PM_{10} emissions such as Parnell *et al.* (1999; 1993) and Sweeten *et al.* (2004), have made use of the assumption that PM_{10} behaves as a gas. This assumption simplifies the modelling process as the effects of deposition can largely be ignored. However, the downside to this is that PM_{10} does not behave like a gas. The smaller fraction ($<PM_5$) behaves like a gas, however with distance from a source the larger particles will drop out of suspension. Accordingly, the use of this assumption may result in erroneous data if the sample point is far enough away from the source. In this instance, the samples were collected immediately downwind of the feedlot pens, reducing the chance of the large particles settling. Thus the use of the assumption remains valid.

7.4.8 Surface roughness

Roughness height is a standard input into dispersion models and allows the modeller to represent the presence of features in surrounding area. The variation likely in this parameter make it extremely important in dispersion modelling (Smith 1993). The further away from the source, the more important this feature would be (Harris *et al.,* 1996). Figure 29 shows a typical feedlot pen with fencing, feed bunk, cattle and shade structures.

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Figure 29: Cattle in pens with vegetation in the background

In the absence of in depth meteorological measurements, the surface roughness of the site was based upon the 1/10th rule of thumb and a value of 15 cm was selected. Kelly *et al.* (1994) investigated the aerodynamic roughness of an Australian feedlot in the 1990's. They determined surface roughness using vertical temperature and wind speed profiles. Whilst using the 1/10th rule of thumb, they expected a 15 to 20 cm surface roughness; in reality they found that the cattle and fences did not overly influence the surface roughness of the feedlot. Their work found the surface roughness to be 1.160.3 cm.

With back calculation, the higher the surface roughness the higher the back calculated emission rate. Thus as the modelling was undertaken using a roughness height of 15 cm, the modelled emission rate is likely to be on the upper limited of the actual emission rate.

7.4.9 Summary

The modelling yielded an average emission rate of 23613 kg/day/1000 head. This value is approximately half of the current NPI emission rate estimates. As discussed above a number of the assumptions used in the model would result in the modelling producing an overestimate of the real emission rates (i.e. surface roughness, background PM_{10}).

However this approach does have a number of limitations, namely:

- the actual number of cattle was based on pen size and stocking density, not actual numbers;
- samples were only taken during one week;
- the sampling does not take into account seasonal variation (winter emissions are apparently higher in the United States); and
- the whole feedlot was not modelled.

Whilst these limitations are present, the over prediction of emissions via other assumptions leads towards this data providing realistic emission for an Australian feedlot.

7.5 Dust fall

Dust fall is used to indicate the potential of dusts to cause nuisance. However, the technique is only an indicator method, with various sources of error (Bardsley 2000). Dust fall gauges trap particulate matter bigger than 50µm in size as these particles tend to be deposited close to their source. It is the insoluble fraction of the collected dust that causes most complaints (Bardsley 2000). Rather than being used with a defined regulatory value, dust fall is often used to trigger the use of more intensive, high volume or real time methods.

When comparing the meteorological data as a wind rose and the fallout data it is important to remember:

- Poor correlation between wind speed and direction against dust fall, local sources of dust are likely to be the dominant contributors thus no trend for the entire feedlot; and
- Higher correlation between dust fall and meteorological data, finer particulate sources, which may travel further are likely to be the dominant sources and can contribute over a wider area.

Bardsley (2000) concluded that when comparing dust fall values, meteorology over the sampling period should be assessed to decide if weather conditions were comparable and that the best ways to assess dust fall were graphical illustration of the means over time against limits or contour plots. Bardsley stated, “*The important feature of collecting meaningful dust fall data in a survey is to adopt a standardised approach which will enable valid comparisons to be made*”. Over the 12-month project period, a standardised approach was undertaken giving the project team a representative dataset. The results of the insoluble solids and percent combustibles are discussed further below.

7.5.1 Insoluble solids

Insoluble solids are often used to monitor potential sources of dust emissions and nuisance sources (Vallack and Shillito 1998; Bardsley 2000). In a feedlot, insoluble solid concentrations would be expected to be greatest closest to the feedlot or directly downwind of the feedlot, due to the larger particles dropping out of the air faster than smaller particles. Thus, the influence of the pens that contribute dust should diminish with distance. It would be expected that the intermediate and background sites would have low levels of dust fall.

Roadways can be a significant source of particulate matter (Wanjura *et al.,* 2004) and, thus, high levels could be expected near them as well as sites close to the feedlot pens. It was interesting to note that sites 1 (background) and 2 (roadway) in Figure 18 appeared to be higher than the feedlot and other sites over the project period. The box and whisker plot for the sites (not shown for sites 1 & 2) indicated that these sites were different to all other sites.

Rainfall would be expected to reduce dust fall by suppressing dust emissions and by scavenging dust from the air when contact between the rain and dust occurred. No relationship (R^2<0.1) was observed between the mean monthly rainfall and mean insoluble solids levels over the project period. At first glance, the data indicates that rainfall does not suppress emissions, in contrast to the data in Figure 7. However when examining the rainfall data in Figure 4, it can be seen that the rain fell over relatively short periods. The real time analysis showed that a single rainfall event could suppress dust emissions for up to 10 hours. Thus, over a period of a month, the rainfall events may have suppressed emissions, but the feedlot appears to have dried out sufficiently for dust concentrations to return to “normal” levels shortly after rainfall.

Examining insoluble solids at the project sites by month (Figure 10) showed that September 2003, October 2003, February 2004 and May 2004 appeared to be higher than the other months. December 2003 and January 2004 were not analysed due to high rainfall.

Over the project period, when viewed by group, it is apparent that the feedlot and intermediate sites had very consistent insoluble solids levels (Figure 11). The months also had low variability between them. From this it can be concluded that the processes driving the emission and transport of dust within the feedlot remain relatively constant over time, whereas, the roadway and background sites are more likely to be influenced by other factors, such as vehicular transport and seasonal agricultural activities. The field notes indicated that silage was often hauled along the road past site 2. It is likely that the intermittent use of the road is the cause of the variations observed. The data indicates that, irrespective of what occurs within the feedlot, little variation occurs in insoluble solids levels in the feedlot and the area immediately around the pens.

A linear regression was performed on the insoluble solids and wind run data, which showed a correlation (R^2) of 96% with insoluble solids deposition decreasing as wind run increased. The months were also analysed using an ANOVA to look at statistically significant effects. The ANOVA showed that there was a significant difference ($P<0.05$) between groups for the months of November 2003, February 2004, March 2004 and April 2004. No other months showed a significant group effect. By examining these months with respect to onsite activities, it would be expected that the differences could be accounted for. The results of further analysis on these months are discussed below.

7.5.1.1 November 2003

November 2003 had a similar average insoluble solids level compared to other months. When looking at the grouped data for the month (Figure 14), it was apparent that the feedlot sites had the highest solids levels for the month. The results showed that the feedlot sites had the highest dustfall, followed by road, intermediate and, lastly, background sites. An example of the pens during the month is shown in Figure 30, and one of the feedlot funnels prior to wash down is shown in Figure 31.

Figure 30: Sample site 8 – November 2003

Figure 31: Fallout funnel at site 9 – November 2003

The field notes and photos showed that the feedlot sites were very dusty (thus higher insoluble solids levels) during that month. During the site visits, it was noted that there was only stubble in the paddocks near some of the sites (2, 3, 4, 11, 16). As the background average was low, it is unlikely that harvesting or other associated activities occurred. The meteorological data for the period is shown in Figure 32.

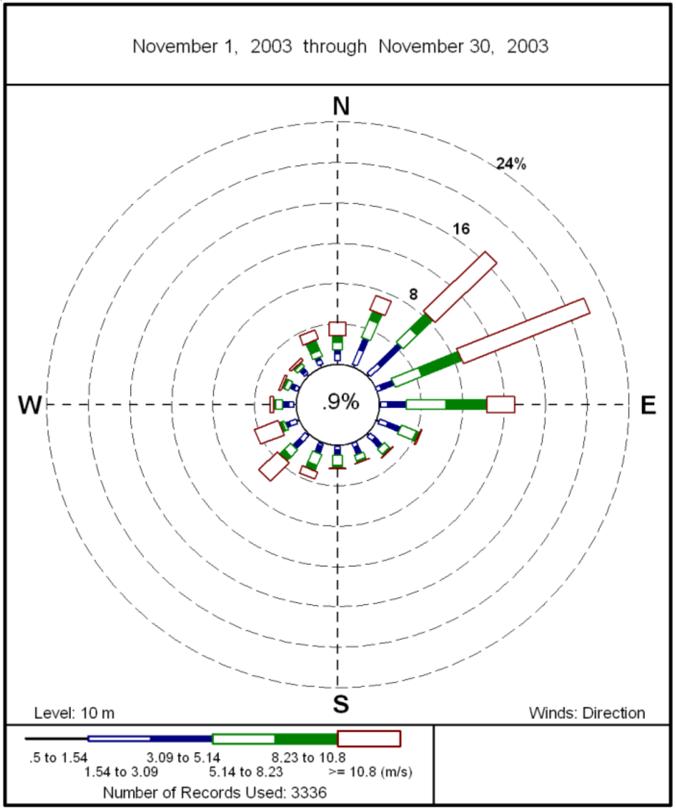

Figure 32: Windrose for the feedlot, November 2003

Figure 32 shows that:

- the majority of wind came from the north east and east of north east; and
- less than 1% of the wind speeds (10 minute averages) for the months were below 0.5m/s.

The 0.5 m/s cut-off for wind speed is used as cup and vane anemometers tend to be unable to accurately measure wind speed below this value. The windrose indicates that dust emitted from the feedlot, once airborne, would have travelled southwest and the greatest dust fall levels could be expected at sites in this direction (i.e. 6, 9 and 17). As feedlot sites had the highest dust fall for the month, it was apparent that this was the case. This can be clearly seen in the contours in Figure 33 below. The background sites, which were all located in a southerly direction from the feedlot, had the lowest dust fall for the month.

Figure 33: Contour plot of insoluble solids levels for November 2003

High dustfall was measured at site 2, thus site 2 was not included in Figure 33 as it had a large effect on the measured contours. The contours show that, whilst the feedlot sites had high dust fall, the levels to the west of the site dropped off with distance from the feedlot pens.

7.5.1.2 February 2004

Insoluble solids levels for February 2004 were similar to other months but, in addition, had an above average rainfall for both the project period (59 mm) and the historical mean rainfall of 49 mm per month. The grouped data for the month (Figure 15) showed that the roadway sites had much higher dust fall than the other sites. The wind speed and direction for the month are shown in Figure 34 and the insoluble solids contours for the sites for the month are shown in Figure 35.

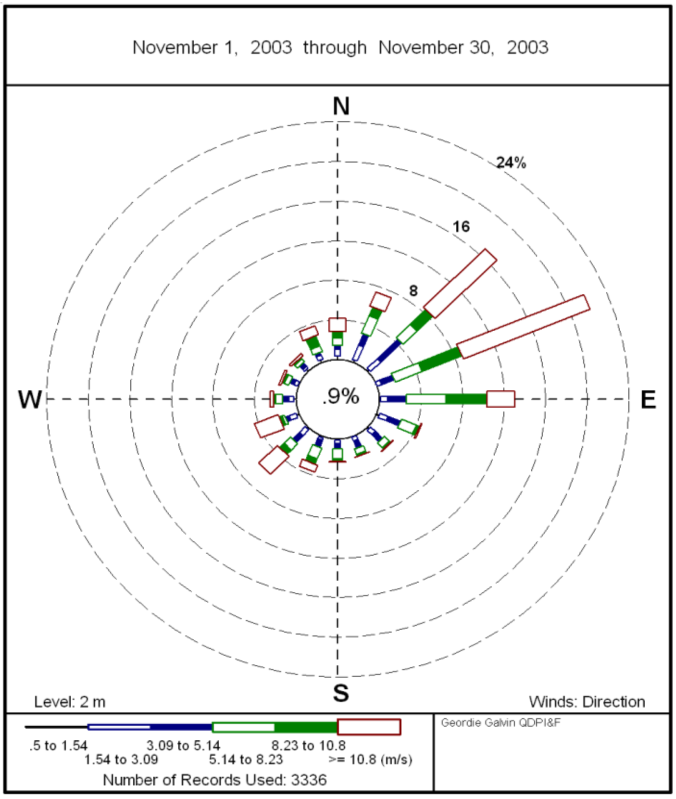

Figure 34: Wind rose for the feedlot, February 2004, measured at 2 metres

Figure 34 shows that:

- February 2004 had a dominant easterly to north easterly component; and
- of the total dataset for wind speed for the month, less than 1% of the 10 minute averaged wind speed was below 0.5 m/s.

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Figure 35: Contours – Insoluble solids February 2004

The contours in Figure 35 show high dust fall at site 13 with dustfall for the month lower at the feedlot and background sites. The dust contours do not correlate with the meteorology, as the dust fall is highest on the south of the site, whereas based on the meteorology, they would be expected to be highest on the south west of the site if the dust was from the feedlot pens. Photos of sites 13 and 14 are shown in Figure 36 and Figure 37, respectively.

Figure 36: Site 13 – February 2004

Figure 37: Site 14 – February 2004

The most likely cause of the higher levels at site 2 and associated sites is the movement of trucks filling the silage pits over that month. Trucks were observed entering the feedlot and travelling past site 2; with the trucks undertaking multiple trips. This would have caused ambient dust concentrations to rise, as observed in the results. The percentage of combustible matter in the dust did not vary by month for the grouped roadway sites (Figure 21) and for the entire project site 2 had low percentage of combustible matter (Figure 20). This indicated that the dust trapped at site 2 was from a source with lower organic matter than the feedlot.

7.5.1.3 March 2004

March 2004 had a lower average insoluble solids value to the previous month and less rainfall occurred during this month than the previous month. The means showed that the roadway and background sites had the highest fallout during this month, followed by the feedlot and intermediate sites. The meteorology for March 2004 is shown in Figure 38. This direction is similar to that seen in the previous month. The contour plot for insoluble solids levels for March 2004 is shown in Figure 39.

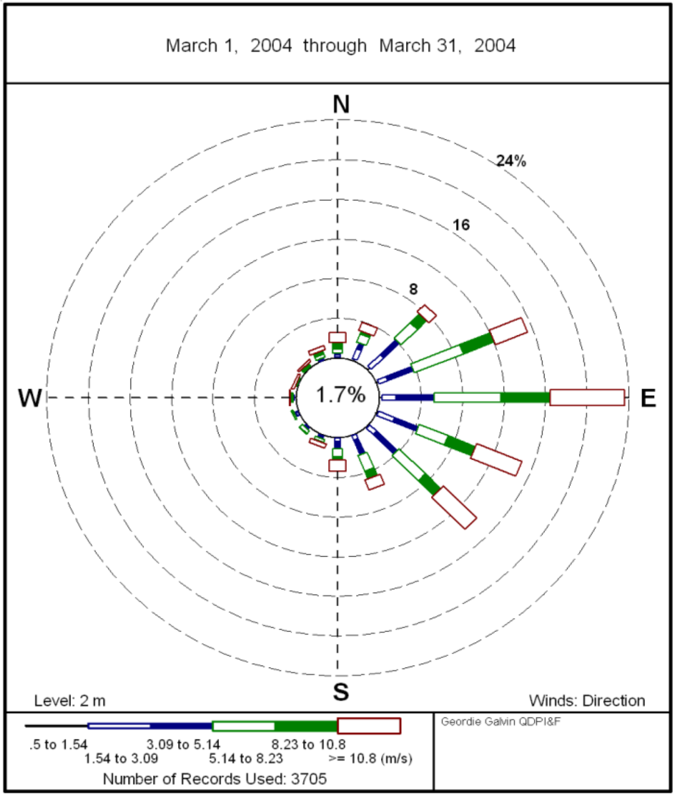

Figure 38: Windrose for the feedlot, March 2004

Figure 38 shows that

- for the month, 1.7% of values were below 0.5 m/s; and
- the wind blew predominantly from an easterly direction.

Figure 39: Insoluble solids contours – March 2004

Based on the meteorology it would be expected that if the feedlot were the dominant source of particulates, sites 6, 9, 15 and 17 would have high values as they are to the west of the feedlot. The sites with the higher values include sites 2, 3, 4, 13 and 16, which were located outside of the feedlot and to the south. The meteorology showed that the pens were not the dominant source during this month.

The field notes signalled that cultivation occurred near the road sites and from this it is assumed that these activities may have generated dust, thus the higher values measured. The percent combustibles for the grouped sites for the month showed that the feedlot, background and roadway groups had higher levels than the intermediate sites. On average, the feedlot and intermediate sites had higher amounts of combustible matter, possibly due to sources of dust within the feedlot, such as dust from the pens and feeding of animals.

7.5.1.4 April 2004

April 2004 had a similar average insoluble solids value to the previous month. It also had less rainfall than the previous months. The meteorology for April 2004 is shown in Figure 40. Figure 41 shows the contour plot for insoluble solids levels for March 2004.

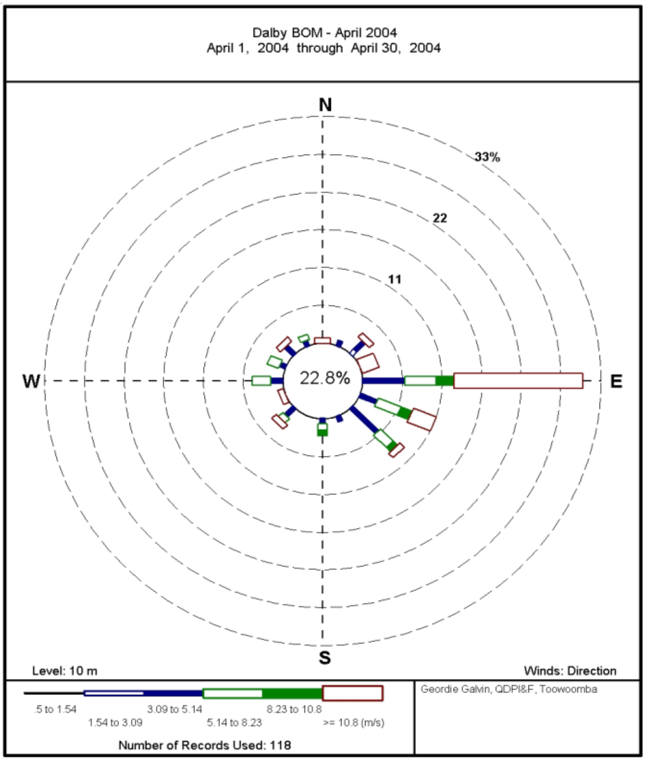

Figure 40: Windrose for Dalby – April 2004, measured at 10 metres

Figure 40 shows that:

- for the month, 23% of the wind speed values were below 0.5 m/s; and
- the wind blew predominantly from the east.

Figure 41: Insoluble solids contours – April 2004

The contours in Figure 41 indicate high dust fall in the centre of the feedlot. This was confirmed with the means showing that the feedlot had the highest levels, with the intermediate, roadway and background sites being similar. Based on the meteorological data it would be expected that the sites in the centre and on the western edge of the feedlot would have the greatest fallout levels, as the wind would blow dust toward the west. This was supported by the data.

7.5.1.5 Summary of insoluble solids results

The insoluble solids results presented in this report provide an insight into dust deposition around a large feedlot. Generally, the measured dust levels at sites outside of the feedlot area (i.e. intermediate and background) did not appear to be directly related to the feedlot as the background sites, as they were often higher than the other measurement sites. Based on the results, the following observations have been made:

- the feedlot and intermediate sites were consistent with respect to deposition rates and variation between months over the project period;
- the roadway and background sites typically had higher dust fall levels and exceeded the reduction in air quality criteria shown in Table 1, whereas, the feedlot and intermediate sites were below this;
- dust deposition rates in the feedlot area fall away sharply with distance from the pens;
- dust deposition at the background sites was higher than feedlot and intermediate sites;
- dust deposition did not appear to be linked to wind speed and direction but was related to wind run; and
- increased dust deposition can be caused by on site practices such as vehicle movements.

7.5.2 Combustible matter

Generally, rural dusts have highly variable organic matter levels compared to low organic matter levels in the soils (Boon *et al.,* 1998). Boon *et al.* (1998) found that on average, 34% of deposited rural dust and 31% of airborne dust was organic. The amount of organic matter trapped in the dust fall gauges should be able to be related to the percentage of combustible matter, as the organic matter would burn off during the analysis process.

Boon *et al.* (1998) heated dust samples to determine their organic content and found that heating dust samples to 375 °C removed organic matter without losing the volatile components of the soil. Their method was similar to the loss on ignition method described by Nelson and Sommers (1996) where a temperature of 400 °C was used. The fallout procedure adopted in this work uses a much higher temperature of 850 °C. Results published by Nelson and Sommers (1996) showed that high temperatures could be suitable for accurately determining organic matter in soils. Based on this information, the combustible matter derived using the dust fall method was used to define the amount of organic matter deposited in the dust fall gauges. For this project, the percentage combustible matter determined for the fallout samples will be considered equivalent to the percentage of organic matter.

As the dust in feedlots would be composed of soil, manure and feed components it could be expected that the feedlot sites would have a higher percentage of organic matter when compared to the background sites. The average amount of combustible matter in the deposited dusts (42%) was similar to the mean combustible matter value published by Boon *et al.* (1998). However, a major difference between their work and this work is that there was less variability (Figure 25) over time compared to the range published in Boon *et al.* of 2 - 90%.

The data does not indicate any relationship between the amount of combustible matter in the deposited dust, and the rainfall over the collection period (1 month). It is apparent that as with insoluble solids, monthly total rainfall does not affect the mean percentage of combustible matter deposited. Whilst the insoluble solids deposition varied with time, the combustible matter remained relatively constant irrespective of rainfall. This indicated that the source of dust on the site remained steady with time. However, the amount of dust emitted (emission rate) varied according to a number of unknown factors but are likely to be associated with site management and meteorological conditions. The specific factors were not evident in the data or field notes collected as a part of this project.

The ANOVA showed that the months of November 2003 and May 2004 were significantly different from all other months, and from each other.

7.5.2.1 November 2003

The percentage of combustible matter for the four dustfall site categories was shown in Figure 23. Statistical analysis indicated that there was a significant difference between the feedlot sites and both the road and background sites. Based on the mean values, the feedlot sites had the highest percentage of combustible matter, followed by background, intermediate and lastly road sites. The field notes and photos showed that the feedlot was very dusty (Figure 30 and Figure 31), during this month. The notes taken in the field during this period did not indicate any reason why the feedlot sites were significantly different to the road and background sites.

The insoluble solids levels shown in Figure 14 for November 2003, did not follow the trends in means as identified in the statistical analysis for the combustible matter, with the roadway having higher insoluble solids than the intermediate sites. This would be expected as the amount of combustible matter (inorganic matter) would be greater near the feedlot where manure pulverised by cattle hooves would be the primary source of dust. Whereas, the roadway with its high soil content would have a lower amount of combustible matter, as the primary source of dust would be the materials from which the road was constructed.

For the month, the meteorology indicated that the wind blew primarily from the north-east (Figure 32). Based on the windrose, if the feedlot were the primary source of dust, it would be expected that this wind would blow the dust from the feedlot westward, resulting in higher combustible matter values for the western feedlot (sites 5, 6 and 17), intermediate sites and possibly background sites (3 & 4). The results in Figure 21 showed that the feedlot sites had the highest amount of combustible matter followed by the intermediate sites, thus, on this occasion the meteorological data and the combustible matter data correlated well.

7.5.2.2 May 2004

May 2004 had a lower total monthly rainfall than the preceding three months. As the data does not show a difference in average percentage of combustible matter, it could be concluded that rainfall does not have an influence on the amount of airborne dust, and, the amount of combustible material in the dust around the site remains relatively constant with time and by source. However, this assumes that the rain falls evenly through the month. Figure 4 showed that the rain for the month fell over a short period toward the end of the sampling period. The poor relationship between percent of combustible matter and rainfall mirrors the poor relationship between insoluble solids and rainfall shown in Figure 10. This is most likely due to the averaging time of one month, whereas methods with daily or less time steps showed that dust concentrations and emitted dusts were suppressed by rainfall.

As local meteorological data was not available for May 2004, meteorology for Dalby was used as shown in Figure 42.

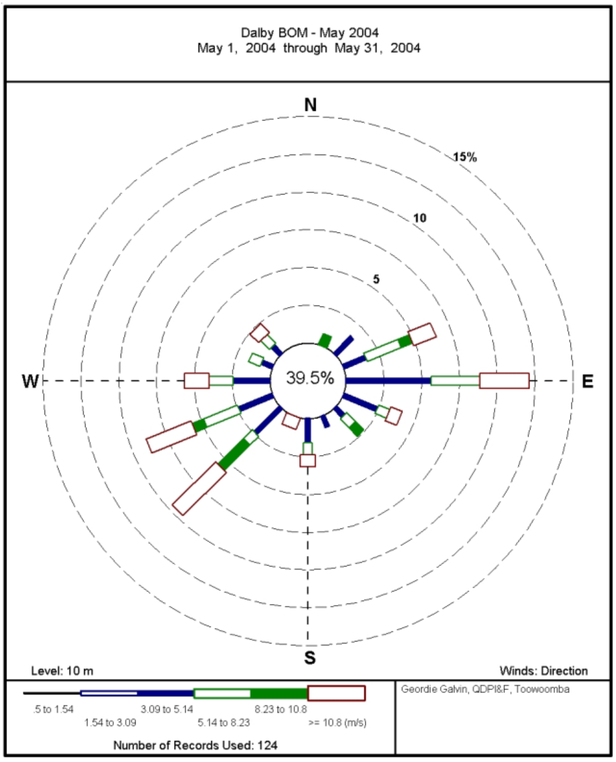

Figure 42: Meteorology for Dalby, May 2004

Figure 42 shows that:

- the wind came from both the southwest and east during the month; and
- 40% of the project period the measured wind speed was below 0.5 m/s.

The wind direction for that month was different from the other recorded months as it had a south-westerly component. The intermediate sites (10, 11, 12 and 14) had slightly higher combustible matter levels than the feedlot sites during that month. These sites were located on the eastern and south-eastern edge of the feedlot. The wind direction data in Figure 42 showed that it was unlikely that the feedlot was the source of the higher percentage of combustible matter. Sites 16 and 13 are shown below in Figure 43 and Figure 44.

Figure 43: Site 16, May 2004

Figure 44: Site 13, May 2004

These sites did not appear to have any activities being undertaken near them that would have resulted in a higher percentage of combustibles. At present, no explanation can be drawn as to why the intermediate sites were higher than the feedlot sites.

7.5.2.3 Analysis of grouped sites

ANOVA analysis on the grouped sites for all months showed no significant difference between the grouped sites. This can be seen in Figure 25 where the box and whisker plot for the grouped sites shows that the boxes overlap. The mean values, as summarised in the box and whisker plots as the horizontal line, showed that the feedlot sites had the highest percentage of combustible matter, followed by intermediate and background, and, lastly road sites.

These results show that the sites closest to the feedlot pens had the highest amount of combustible matter. The data also indicates that the influence of these pens (the amount of combustible matter in the trapped dust) decreases with distance from the pens. The road sites generally had a much lower percentage of combustible matter, indicating that the dust fall at these sites may not have been from the feedlot but from other sources such as the roads.

7.5.2.4 Analysis of individual sites

The ANOVA did not show any significant ($P<0.05$) site effect. The data shown in Figure 25 (left) showed a number of relationships between the ungrouped sites. Where the boxes overlap between sites, these sites are not significantly different from each other. On average, the percent of combustible matter at site 9 (Figure 20) was higher than the other sites. This site was in the middle of the feedlot and, as such, it would be expected that it would capture a large amount of particulate matter from the feedlot pens.

7.5.2.5 Summary of combustible matter results

The combustible matter has indicated a number of aspects about dust in a feedlot, including:

- the amount of combustible matter in the captured dust is highest within the feedlot, with the amount decreasing with distance from the feedlot;
- over a monthly period, there was no relationship between the percentage of combustible matter and total monthly rainfall;
- there did not appear to be a relationship between management practices and combustible matter;
- there was a good relationship ($R^2=0.92$) between the percentage combustible matter in the dust fall and wind run for the months;
- wind direction does not appear to overly influence the percentage of combustible matter at the sites around the feedlot; and
- there was no relationship between insoluble solids levels and percentage of combustible matter in the trapped dust over the project period.

7.6 Comparison of results against standards

7.6.1 Dustfall

As previously discussed, deposition of dust can cause effects such as impaired visibility (Sweeten 1991), and, in certain situations, deposition of dust on clothing and vehicles that can cause damage to the fabrics and metal surfaces (USEPA 1996; Grantz *et al.,* 2003). Vallack and Shillito (1998) concluded that an exact comparison between the different fallout standards used around the world is not possible, which means that comparing the overseas standards with the results from this project is not feasible. A suitable standard to compare the feedlot data with would be that from Western Australia (4 g/m^2/month (loss of amenity) and 10 g/m^2/month (unacceptable loss in air quality).

The results summarised in Figure 10 show that in four of the ten months reported, the mean insoluble solids deposition rate was greater than the 10 g/m^2/month loss of air quality criteria. At first glance, it appears that the feedlot may cause nuisance in the local area. However, this is not the case as when examining the various sites by grouping (Figure 11) the roadway and background sites generally had higher insoluble solids levels than the feedlot and intermediate sites. For the project period the dust fall at the intermediate sites was always below the 10 g/m^2/month value and dust fall values at the feedlot monitoring sites only exceeded this value on two occasions. This indicates that the dust from the feedlot drops out of suspension quickly after leaving the feedlot and it is unlikely that this dust could travel far enough to cause nuisance under normal conditions, provided a moderate separation distance to nearby receptors exists.

7.6.2 PM$_{10}$ emission rates

With load based licensing being adopted in Australia and overseas, savings can be achieved by various industries by having up to date emissions data. Whilst the emission rates in Table 9 were derived over a very short period, they are approximately half of that detailed in the National Pollutant Inventory handbook, *Emission Estimation Technique Manual for Intensive Livestock - Beef Cattle Version 2*. The emission rates were also similar to recent rates published by American researchers. Whilst not conclusive, Australian feedlots appear to emit less fine particulate matter than that shown in the NPI handbook.

8 Success in meeting objectives

The project objectives of this research previously listed covered four areas of research:

- conducting a thorough sampling regime over 12 months to determine insoluble solids and combustible matter levels at sites in and around a feedlot;
- measurement of TSP and PM_{10} every 6 days for a month using high volume samplers;
- examining diurnal variations in the PM_{10} concentrations in the feedlot using real time analysis; and
- assessing the recorded data in comparison to published data and standards.

All objectives were successfully completed and have provided information on dust fall composition in and around an Australian feedlot.

The coarse fraction of the dust was measured at the site over a 12 month period from June 2003 to May 2004, according to AS/NZS 3580.10.1-2003 (Standards Australia 2003a). During this period, all months with the exception of December 2003 and January 2004 were analysed. The samples collected during these months had to be discarded due to the sample bottles overflowing.

In the project proposal, it was suggested that high volume sampling be undertaken every 6th day for a month. This was proposed as daily travel from Toowoomba would have been a large undertaking and may have involved weekend sampling. One of the feedlot staff offered to assist with daily filter changeovers. Therefore, instead of four sampling events over a month, we were able to sample every day for one week (6 sampling days). The PM_{10} data has enabled assessment of the reduction of airborne dust levels in the feedlot associated with rainfall. In addition, during the high volume sampling, diurnal variation was assessed using a DustTrak analyser. Over a three-day period, peaks in dust concentration were noted late in each afternoon. The influence of rainfall on dust concentrations was also observed.

The fallout, total suspended particulate and PM_{10} concentrations were compared to published data relating to dust fall nuisance and the ratio of TSP to PM_{10} in American feedlots. Whilst the fallout data did not show relationships that were related to management factors, it was interesting to note that often the background sites had levels that were as high, if not higher, than the feedlot sites.

Emission rates were determined using a combination of dispersion modelling and real time concentration data. The PM_{10} emission rates were found to be approximately half of that detailed in the NPI handbook for feedlots. Another finding of this work is that the amount of PM_{10} in the TSP concentrations by mass is higher than that previously published, indicating that the dust emitted from Australian feedlots may have different characteristics to the dust found in American feedlots. The difference in the PM_{10} to TSP ratio and the preliminary emission rate data calls into question the NPI emission rates.

9 Impact on meat and livestock industry

The emission of dust is important to the feedlot industry as it impacts on a number of areas including human and animal health and environmental impacts. The data in this report can be categorised into three areas, namely, nuisance potential of feedlot dust, health impacts of feedlot dust and the appropriateness of American emission rate data for the Australian feedlot industry.

The major finding of this work is that the PM_{10} emission rates in the NPI handbook are nearly double that found at an Australian feedlot. Additionally the amount of PM_{10} within the TSP concentrations is higher than that previously published in overseas research. The new emission rates and the PM_{10}/TSP ratio supports the hypothesis that the data upon which the NPI emission rates (i.e. National Pollutant Inventory (2001)) are based are not applicable for Australian feedlots.

The dust deposited in and around the feedlot is unlikely to be directly related to the feedlot as the dust from the feedlot appears to drop out of suspension quickly. The fallout gauges showed no relationship between wind direction and dust fallout both in and around the feedlot. Dustfall measured using dust fall gauges showed that the road and background sites often had higher levels, indicating that the feedlot had a small influence on dust levels around the site. If dust complaints were to occur, this data indicates that it is more likely that the finer fraction of the dust causes the problems, as the heavier particles appear to drop from suspension close to their source.

Published data points toward the finer fraction (i.e. PM_{10}) causing health impacts, thus the health of animals and feedlot workers may on occasion be influenced by prolonged dusty conditions. Whilst this study did not examine dust impacts using personal samplers for both animals and feedlot staff, the data indicates that it is possible that dust concentrations will rise above recognised safe working limits at some stage on site. However, this would depend on the constituents of the dust (Grantham 1992), exposure time and seasonal conditions.

10 Conclusion

The PM_{10}-TSP ratio determined for the feedlot shows more PM_{10} in the total dust concentration than that published for American feedlots. Furthermore the PM_{10} emission rates derived in this research show that the emission of PM_{10} for an Australian feedlot may be half of that published in the NPI handbook. Additionally, the dust fall results indicated that components of the feedlot dust with larger particle sizes did not travel far from their source. This shows that it is unlikely that dust emitted from the feedlot would cause nuisance above that caused by other agricultural sources.

Over a 12-month period dust fall was measured at 17 sites in and around a feedlot. Co-located TSP and PM_{10} samplers were also run daily for a week complimented by real time analysis of PM_{10} using a DustTrak dust analyser. The results were then compared to rainfall, meteorology and activities undertaken on site.

Insoluble solids and the organic fraction of the dust were determined. A linear regression showed that wind run compared well with the insoluble solids and organic fractions over the months. Using the mean monthly fallout data, a linear regression showed no relationship between monthly rainfall and average monthly insoluble solids or combustible levels. When examining insoluble solids (the component that causes complaints), the feedlot and intermediate sites were found to have lower dustfall and lower monthly variability than the background and roadway sites. For combustible matter, variability was observed with respect to time and category over the project period. The percentage of combustible matter was not related to the insoluble solids dust fall levels.

The proportion of PM_{10} with respect to TSP was found to be higher than that published for American feedlots. This in conjunction with the back calculated emission rates, indicates that using American data for the emissions estimation process for the National Pollutant Inventory may not adequately reflect PM_{10} emissions from Australian feedlots. PM_{10} concentrations were found to vary with time with the real time analysis showing over a three-day period, a concentration peak each evening. Published literature and anecdotal evidence indicates that this is due to increased cattle movement associated with decreasing ambient temperatures. During the PM_{10} monitoring period rain fell at the site. It was found that a single rain event suppressed the dust emissions for approximately 10 hours, similar to that seen in recent American research.

Currently, complaints about dust are often associated with afternoon concentration peaks and visible plumes, rather than deposition onto surfaces (*Pers com.* Fletcher 2004). This was confirmed in the results where the dust fall decreased with distance from the feedlot yet was high at the background sites. The background sites did not appear to be influenced by the feedlot. The afternoon peaks were confirmed during the real time analysis indicating the best time for general dust suppression.

Dust fall is an indicator method and as such should be treated with care. Experience in this project has shown that the use of background sites can enhance the data from a project as the background sites indicated that they had higher dustfall than in the feedlot, which was unexpected.

The results have shown that the PM_{10}-TSP ratio is different from American data. Additionally, the back calculated emission rate data confirms that the NPI emission rates may be over estimating true PM_{10} emissions.

11 Recommendations for future research

A number of research themes have arisen from this project. These include:

- undertaking particle size distribution analysis to assess the particle size ranges for typical feedlot dusts to assess the applicability of different dust measurement techniques;
- development of seasonal Australian PM_{10} emission rates for beef cattle feedlots using a combination of direct measurement techniques and back calculation methodology over a summer and winter period; and
- undertaking long term, real time monitoring to compare cattle mortality rates with long and short term particulate exposure.

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