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Prepared by: The Odour Unit Pty Ltd and
Pacific Air & Environment Pty Ltd

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Meat & Livestock Australia
Locked Bag 991
North Sydney, NSW 2059

Determination of meat industry odour thresholds

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

This report addresses the requirements of Meat and Livestock Australia (MLA) Project PRENV.018, 'Determination of Meat Industry Odour Thresholds'.

The Odour Unit Pty Limited (**TOU**), in association with Pacific Air & Environment Pty Limited (**PAE**), was contracted by MLA to conduct a study to identify appropriate odour exposure levels in the communities around meat processing (specifically rendering) plants.

The process of developing appropriate exposure levels involved:

- the sampling of odour sources at each of three study sites and subsequent calculation of odour emission rates (OER),
- odour intensity observations using the German Standard VDI 3882 odour intensity scale (see section 6.2 for more details) at various locations in the area surrounding each study site;
- a review of odour complaints made against each participating facility;
- modelling of odour dispersion from the measured sources; and
- evaluation of odour levels at which odour complaints and annoyance appear to be triggered, on the basis of the available data.

Representatives of TOU and PAE jointly visited each of the facilities. Broadly, TOU was primarily responsible for the determination of odour emissions from the facilities, and PAE was primarily responsible for the odour modelling and assessment component.

2 Study Sites

Three meat processing plants were selected to participate in the study. They are:

- Plant 3, Locality 3, NSW;
- Plant 2, Locality 2, NSW; and
- Plant 1, Locality 1, Queensland.

3 Background Information

3.1 Odour Nuisance and Assessment Principles

3.1.1 Odour Sensation and Perception

Odour is a sensation that can be caused by a great variety of gaseous compounds. When odorous compounds, or odorants, are present in sufficiently high concentrations in the air, they trigger responses in individuals who are exposed to them.

Odour sensation involves a complex process of reception and interpretation of signals in the brain. It is initially triggered by the presence of odorants that reach the olfactory nerves in the epithelium, in the upper portion of the nose. These nerves form the only part of the brain that is exposed to, and directly senses, the external environment. Various types of nerve in the epithelium are excited by different odorous chemicals. There are far fewer nerve types than odour types, and so the signals that flow from these nerves to other parts of the brain involve various combinations and sequences of nerve firing. A specific odorant mixture will send a unique set of signals. These signals are then processed in a complex way, which includes the use of memory to recognise and interpret the odour. In this process of interpretation the odour may be associated with past events, and this can invoke strong emotional responses.

Whether an odour is perceived as pleasant or unpleasant (i.e., its hedonic tone) depends on the nature of the substance(s) involved and, importantly, it also depends on the perception of the individual. Although most people agree that specific odours are either pleasant or unpleasant, this is not always the case. Differences between individuals in the assessment of an odour's hedonic tone can arise from differences in both physiology (for example, genetic factors or injury to the olfactory system) and experience. Hedonic tone is a factor in determining whether the odour is likely to cause annoyance. However, it is not the only factor. For example, the same odour at different strengths can change from being pleasant to offensive.

Perception is important in explaining why some people are annoyed by particular odours and others are not. In addition, physiological sensitivity to odour varies in the general population and some people are at least 100 times more sensitive than others. This can help to explain why sometimes only isolated individuals in a community seem to be annoyed by odours. Again, however, the often-observed patchiness of annoyance or complaints in a community is not simply caused by the combination of perceived odour character or strength. Community dynamics also play a part.

3.1.2 Annoyance and Complaints

The main adverse effect of environmental odours is annoyance. People generally become annoyed by an odour that they regard as unpleasant and from which they cannot readily escape. Repeated exposure to annoying levels of odour results in nuisance. Long-term exposure to highly annoying odours may cause some physical symptoms that are related to stress, and the receiver may become particularly sensitive to the odour. Section 3.1.4 contains more detailed discussion of odour sensitisation and associated effects.

Complaints generally arise when the odour causes a high level of annoyance. However, this is not necessarily sufficient to lead to complaint, and in some cases it may be that the odour problem has become so chronic or entangled with other issues that complaint can arise even when the odour is not particularly strong. Complaints often involve a reasonably high level of emotional response, and a variety of factors can lead to a situation where complaints do not accurately reflect the severity of an odour problem. Some features of complaints that are relevant to assessing odours are:

- Generally, complaints are made when people feel that there is something to be gained by complaining. Often, this simply involves bringing attention to the problem and having it rectified. However, in some cases, particularly those that are more long-term and less easily resolved, the motivation for complaining may be more complex and may include putting political pressure on the source of the odour.

- The absence of complaints does not necessarily signify that odour is not a problem. In some situations, it may be apparent to the community that complaints will not achieve the desired action and hence the level of complaint may be low.

- In some communities, complaints may be channelled through informal representatives. In these cases, complaints may be dominated by a small number of individuals who reflect a broader group of annoyed residents.

Because of the many influences on complaints apart from the physical manifestation of the odour, it is unwise to rely on complaints as an accurate indicator of the extent and severity of an odour nuisance problem. Complaints should be analysed carefully to ensure that anomalous conclusions are not made about the situation. For example, often a careful analysis of complaints reveals that some odour complaints coincide with times when the odour-generating operation in question was inactive. Identifying the sources of complaints can be complex and inconclusive without detailed, relevant information.

3.1.3 FIDOL and Other Factors Affecting Odour Response

Analysis of community odour exposure has identified five factors that are important in determining the potential for annoyance and complaint:

- Frequency;
- Intensity;
- Duration;
- Offensiveness, and
- Location.

These are together called the FIDOL factors (NZ Ministry for Environment, 1995). Generally, the greater the frequency, intensity, duration and offensiveness of an odour the more likely it is to cause annoyance and lead to complaints.

Frequency

The frequency of odour exposure simply refers to how often odour events occur. It is a function of the variations of odour emissions over time, and of the meteorological conditions in the area around an odour source. The frequency of odour events is generally greatest in areas that are most often downwind of the source, especially under light wind and stable atmospheric conditions (provided that the odour is not emitted at a significant height above the ground).

Although the frequency of odour events is a prime determinant of the likelihood of nuisance occurring, the timing of events can also be important. There are times of the day, for example, when there may be a greater likelihood of people being exposed to any ambient odour, such as in the morning period around breakfast or around the evening mealtime. At other times, the likelihood of being away from the home, or asleep or simply inside with windows and doors shut may reduce the likelihood of being affected by odours that are present in the ambient air.

Intensity

The intensity or perceived strength of an odour is related to the odour concentration, or the mass concentration of the compounds involved. However, the relationship is not direct.

A standard scale for describing odour intensity is detailed in the German Standard VDI 3882 (I). The odour intensity scale is summarised in Table 3.1.

Table 3.1: **German VDI 3882 Odour Intensity Scale**

Odour intensity	*Intensity level I*
Extremely strong	6
Very strong	5
Strong	4
Distinct	3
Weak	2
Very weak	1
Not perceptible	0

For simple odours associated with single compounds, such as hydrogen sulphide, the relationship between the intensity and the mass concentration of the compound ($\mu g/m^3$) or its odour concentration (ou), has the general form of a power law or a logarithmic relationship. Thus, as the odour concentration increases, the perceived strength or intensity increases by a much smaller amount.

The relationship between odour intensity and odorant concentration may be described by the Weber-Fechner law (Frechen, 1997), which is written as:

$$I = k_w \log(C_{OD})$$

where

I	= intensity level
k_w	= Weber-Fechner coefficient
c_{OD}	= odorant concentration

The detection and perception of odour usually arises from the presence of mixtures of chemical compounds, and a simple additive effect of individual odour concentrations generally does not apply. Owing to differing intensity-concentration relationships for various constituents of a complex odour, the dominant odorants giving rise to the odour's character can change with varying concentration of the odour, even though the relative concentrations of the various constituents remain the same.

An example of an odour intensity-concentration curve is shown in Figure 3.1. Note that concentration (on the x-axis) is plotted on a logarithmic scale. Schulz (2002) describes the determination of odour intensity and provides examples of intensity-concentration relationships for specific sources.

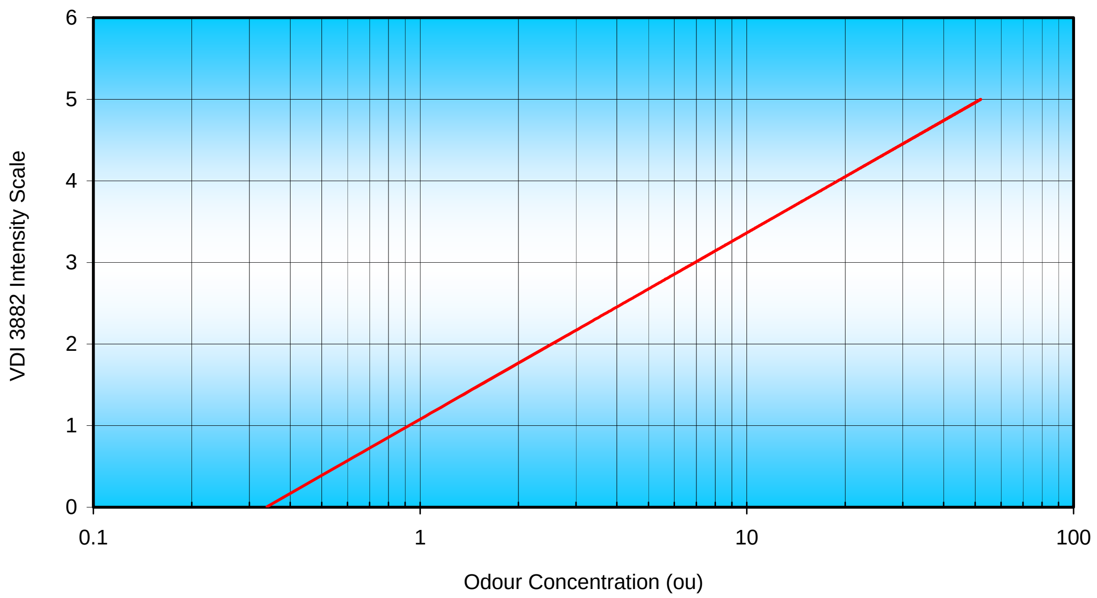

Figure 3.1: Example of odour intensity-concentration relationship

This non-linear relationship is relevant when interpreting modelling results. Dispersion modelling of odour deals with odour concentration, rather than intensity.

Duration

The duration of odour events is controlled mainly by meteorological conditions, although variations in odour emissions may also be important for sources that vary in strength over short time periods. Longer duration odour events are likely to be associated with more stable meteorological conditions, which tend to be common at night and around sunrise and sunset. Somewhat persistent odour events appear to be generally more likely to cause annoyance than very brief single exposures, although this may simply reflect the general distribution of types of odour sources (which have different types of impacts). Desensitisation or habituation can occur during a substantial period of continuous exposure.

Under some circumstances, an odour ‘event’ may comprise intermittent, short periods of detectable odour interspersed by periods when no odour is detectable. Such behaviour is most prevalent when the odour is emitted during neutral to unstable (convective) meteorological conditions, especially when the source is elevated (e.g., a stack). The intermittent presence of the odour at downwind locations reflects the influence of atmospheric turbulence on the plume’s behaviour.

In cases where the intermittency or fluctuation of the odour is a significant feature (e.g., in relation to sensory thresholds), then some means of representing the odour fluctuation statistics may be important to adequately describe the relationship between odour intensity or concentration and the potential for annoyance or complaint. To address this issue, the New South Wales EPA incorporates the concept of peak-to-mean ratios into the quantification and assessment of odour impacts.

Offensiveness

Offensiveness is a subjective or qualitative aspect of an odour, relating to its intrinsic pleasantness/unpleasantness or underlying quality. There is often confusion about the term, because there is a tendency to regard offensiveness and related terms (e.g. hedonic tone) as a function of the odour intensity. However, for proper evaluation of offensiveness as an intrinsic characteristic of an odour, it should be evaluated independently of intensity or concentration. Some researchers have attempted to quantify odour offensiveness, by presenting odour of a known concentration to panellists and asking them to rate the offensiveness on a scale, in a somewhat similar way that odour intensity is quantified (e.g., Lott, 1992).

Location

Location is an essential consideration when assessing the likelihood of odour nuisance. People working within industrial environments are generally expected to be less concerned about odours than people within their home environment, or involved in recreation. There are some less straightforward situations: for example, where people travelling past odorous activities may consider the odour to be unacceptable, even though it is not impinging upon their residential property. This is an area that is not well resolved in terms of assessing the validity of complaints about odorous activities, but odour assessment generally places greatest emphasis and importance on odours at residential sites.

Individual responses to particular odours can be influenced by other factors such as:

- State of health (for example, tolerance may be reduced if feeling unwell. Illness can also inhibit the ability to escape the odour, which will increase annoyance);
- Previous experience (persistent history of odour events is likely to be met with greater hostility); and
- Relationship with the enterprise generating the odour (for example, if the person gains income or other benefits from the enterprise, the perception may be more positive. On the other hand, if negative experiences with the enterprise have occurred, the response may be less tolerant).

Of the factors outlined in this section, quantification through measurement and modelling of odours can address frequency, intensity and duration. Typically, the odour concentration and not the odour intensity is addressed, but this is of minor consequence unless the odour has an unusual intensity-concentration relationship. Odour offensiveness is not routinely addressed in a quantitative sense.

3.1.4 Odour Impacts in Sensitised Communities

In order to better understand the nature of an individual's response to odours it is helpful to understand two concepts that occur in all sensory systems: adaptation and sensitisation. Adaptation is a reduction in responsiveness (i.e. a rapid decrease in perceived intensity) during or following repeated exposure. Conversely, sensitisation results in increased responsiveness during or following exposure.

Adaptation to odours can occur on either a short term or long term basis. Short term adaptation primarily occurs as a result of odorous chemicals inducing a short refractory period during which further stimulation is limited (sometimes referred to as 'olfactory fatigue'). Long term adaptation results in more persistent reduction in response that can be measured hours or even days following exposure and can account for situations where persons who work in odorous environments cannot fully comprehend complaints from neighbours who only receive intermittent odours (Schiffman, 1998).

Conversely, individuals who may not be particularly sensitive to odours may become sensitised to olfactory stimulants through acute exposure events or as a result of repeated exposure to nuisance levels of odours. Often symptoms such as headaches, nausea, throat irritations and sleeplessness are reported at exposure levels barely exceeding the odour threshold.

Shusterman *et al*. (1991) suggest that a link between environmental odours and 'environmental worry' may help to explain apparent physiological symptoms reported in populations exposed to concentrations well below levels at which classical toxicology predicts any irritation or adverse health effect. This effect may be explained by mechanisms such as biologically intrinsic odour aversions (the concept of predictable, inherent odour response to certain stimulus), the exacerbation of underlying medical conditions (such as asthma or morning sickness) or conditioned responses (known as 'behavioural sensitisation').

'Behavioural sensitisation' is well documented for cases of acute overexposure to odorous substances in the workplace. The odour may be well tolerated before acute exposure but act as a trigger for recurrent anxiety or hyperventilation symptoms afterwards. In some cases, similar involuntary responses may also be triggered by odours from other chemicals to which no known aversive conditioning has occurred.

Shusterman *et al*. (1991) concluded that far from being a neurotic process, behavioural sensitisation to odours is an adaptive or protective response with minimal, if any volitional or personality component. Similar response mechanisms have been observed within communities strongly opposed to, or affected by the siting of municipal, industrial or agricultural odour sources.

Dalton (1996, 1997) reported that beliefs about the safety of an odour can have an effect on its perception. In Dalton's clinical studies, groups of people were exposed to odours in a test chamber. One third of test subjects (the 'positive' group) were told that the odour was a natural extract used by aromatherapists, another third (the 'negative' group') were told the odorant was an industrial chemical which purportedly caused health effects after long exposure, while the remaining third (the "neutral' group') was told the stimulant was a common, approved stimulus for olfactometry experiments. The 'positive' group showed normal adaptation over the test period, that is the perceived intensity decreased over time. However, the 'negative' group rated the strength of the odour as increasingly greater after an exposure of 10 minutes, which was illusory as it actually remained constant over time. Overall, the negative bias group found the odours to be more irritating and had the greatest number and intensity of health symptoms, including nose, throat, and eye irritation as well as light headedness.

Symptomatic response to perceived health risks was also studied by Knasko *et al.* (1990) in a study of the behaviour, physical well being, and emotional state of persons in a room that supposedly contained odour but really did not. People who were told that the room contained a malodour reported a more negative mood and more symptoms of discomfort than persons told that the feigned odour was pleasant. This study, like those of Dalton, showed that cognitive expectations about odour and irritation can influence sensory perception.

A number of studies conducted in communities surrounding municipal, agricultural and industrial odour sources such as those reported by Schusterman (1992) confirm that community odour impacts can extend beyond mere nuisance and annoyance effects, producing a range of physiological symptoms including headache, nausea, eye and throat irritation, and sleep disturbance. A common feature of many of these studies is that measured or modelled exposures to airborne toxicants report levels well below those known to cause acute symptoms by recognized toxicological mechanisms. The available evidence suggests that enhanced odour recognition can occur as a result of remembered or learned experiences.

The degree to which individual sensitisation can be influenced by community interactions (or group processes) is not well understood. However, it is postulated that community sensitisation may be 'transmitted' via normal or extraordinary communication processes. These communications may be either internal (between community members) or external (such as via media reports). Negative images (i.e. those that transmit messages of concern, dismay, distrust, adverse health impacts, etc) are likely to be more influential in increasing adverse reactions in the receiver. Thus community interactions may help explain the occurrence of localised 'hotspots' in which the occurrence of sensitised individuals may exceed the expected probability.

4 ODOUR ASSESSMENT CRITERIA

4.1 General concepts

In attempts to quantify the odour levels that provide reasonable protection against community odour annoyance, various regulatory authorities in Australia and elsewhere have developed numerical criteria for the evaluation of odour impacts. However, no widely accepted criteria have yet been developed for the assessment of odour impacts. This reflects the difficulties of odour sampling, measurement and modelling, combined with the lack of suitable data on odour levels associated with annoyance and complaints. Assessment criteria have changed substantially over the past decade, in response to changes in the understanding of odour nuisance and odour quantification.

Key elements of quantitative odour criteria that are used for planning purposes are:

- Concentration;
- Averaging time; and
- Percentile value.

Concentration is the odour strength as determined by dynamic olfactometry.

Averaging times for odour criteria are generally either 1 hour or 3 minutes. Dispersion models that are used for predicting or simulating odour concentrations utilise a basic time interval of one hour for individual calculations. For smaller averaging times, the 1-hour result is converted using a statistical relationship between concentration and averaging time.

The **percentile value** refers to the percentage of time (usually over a full year) during which the actual odour concentration must be within the criterion concentration.

The shorthand notation incorporating these parameters is written in the form $C_{p,t}$ where C is the concentration and the subscripts p and t refer to the percentile value and the averaging time, respectively. For example, $C_{99.5,\ 1\text{-hr}}$ refers to the 99.5th percentile 1-hour average concentration. If we write $C_{99.5,\ 1\text{-hr}} = 5$ ou, it indicates that the 99.5th percentile 1-hour average concentration is 5 ou, meaning that for 99.5% of the hours in the year, the 1-hour average concentration should not exceed 5 ou. A corollary of this is that the 1-hour average concentration may exceed 5 ou for the remaining 0.5% of the hours in the year (i.e., 44 hours in the year).

The percentile approach involves the setting of an odour concentration that is equated to a specific percentage of the time (over a full year) during which the actual odour concentration may exceed the stated criterion concentration. The various state odour criteria are expressed in terms of differing percentiles and averaging times. Percentile values currently used in Australia range from 99th to 99.9th (C_{99} to $C_{99.9}$). However, in recent times some specific industries such as the pig industry have proposed use of the 98th percentile (C_{98}) in line with common practice in Europe.

The use of a percentile value does (or should) not imply that there is a proportion of hours in the year when odours can be unacceptable. In any given situation, the odour concentration exceeded for 0.5% of the time will be higher than the concentration exceeded for 2% of the time. The percentiles and corresponding odour concentrations can be plotted on a curve, an example of which is shown in Figure 4.1. (Note that in Figure 4.1 the percentage of time equalled or exceeded is equal to (100 – p), where p is the percentile value. For example, the $C_{99.5}$ concentration equals the concentration equalled or exceeded for 0.5% of the time). The curve plotted in Figure 4.1 displays a hypothetical 'criterion' curve, along which any point is assumed to be equivalent to another in terms of the level of odour exposure experienced over the long term. Hence, by referring to Figure 4.1, it can be seen that to change from one percentile to another as a policy criterion simply requires making the change to the corresponding odour concentration along the curve. In other words, if a criterion is expressed in terms of a concentration not to be exceeded 0.1% of the time ($C_{99.9}$), then there is an equivalent criterion that can be expressed as, say, C_{99} with a lower concentration value.

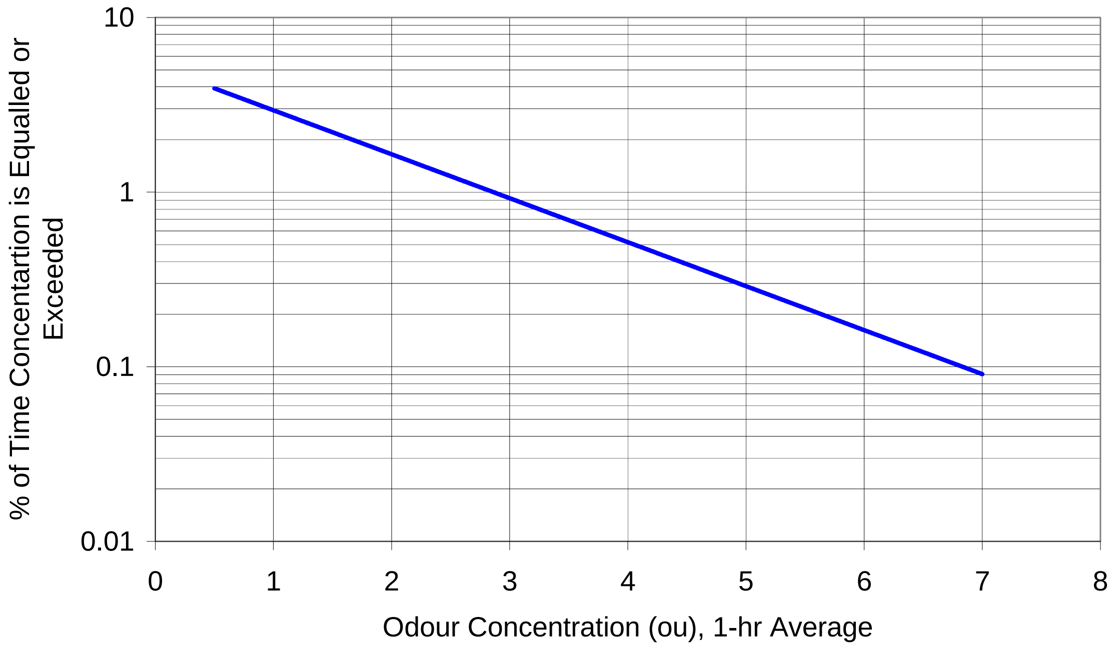

Figure 4.1: Hypothetical 'acceptable limit' curve of odour concentration vs frequency-of-exceedance (see text for discussion). Note: the actual concentration values in the graph are not proposed as actual criteria, but are for illustrative purposes only.

4.2 Expression of criteria in common terms

The various state odour criteria, described in following sections, are expressed in terms of differing percentiles and averaging times, and differing regimes of application. To convert the criteria to a common basis (percentile and averaging time) is, strictly speaking, dependent on site-specific meteorological conditions. Hence, any generic listing of the criteria on a uniform basis is necessarily only a crude approximation.

Dispersion model predictions are based on hourly averaged input data and, by default, models generate 1-hour average predictions of ground level concentrations. Conversion to shorter periods (e.g., 3 minutes, 1 second) relies on empirical relationships, i.e., simple conversion factors.

To express 3-minute criteria as equivalent 1-hour average concentrations and vice versa, the usual method of converting modelled concentrations involves the use of Turner's power law, which relates the concentration $C(t_1)$ averaged over time period t_1 to the concentration averaged over time t_2 as:

$$C(t_1) = C(t_2)\,[t_2/t_1]^p$$

where p is an exponent typically set to 0.2 in Australian regulatory modelling practice. However, the actual value of p in any situation is site-specific. For example, values for tall stacks are typically greater than 0.3, and for non-point sources values of around 0.14 have been noted.

To convert 1-hour averages to the nose-response time (~ 1 second) used in the NSW criteria, peak-to-mean ratios have been developed for general application. These ratios are a function of source type, meteorological conditions and distance from the source. Guidance on use of the peak-to-mean ratios is contained in the NSW odour policy document (NSW EPA, 2001).

Conversion between percentiles (e.g. from the $C_{99.0}$ used in NSW to the $C_{99.9}$ used in Victoria, SA and WA) is not straightforward, since ratios between percentile values are strongly site-dependent. Even around a single odour source, the ratio between, say, the $C_{99.0}$ and the $C_{99.9}$ value will vary with direction and distance from the source. For example, at locations that are frequently downwind of the source under adverse dispersion conditions, the $C_{99.9}$:$C_{99.0}$ ratio will generally be much be lower than at locations that are only rarely downwind under adverse dispersion conditions.

Bearing these considerations in mind, approximate odour criteria based on a 1-hour averaging period and 99.5th percentile (i.e., $C_{99.5,\ 1\ hour}$) can be estimated as follows:

$$C_{99.9}:C_{99.5} = C_{99.5}:C_{99.0} = 2$$

Note that for criteria other than those originally expressed as $C_{99.5}$ values, the error in the approximation may be significant (greater than a factor of 2). However, the general ratios $C_{99.9}:C_{99.5} = C_{99.5}:C_{99.0} = 2$ are a rough rule of thumb often approximately satisfied at specific sites.

4.3 Current Australian Odour Criteria

The following sections summarise odour assessment criteria currently in place in Australian jurisdictions. Note that all criteria used by regulatory authorities are intended primarily for planning rather than compliance purposes. There is evidence from Australia and overseas to suggest that actual odour exposure levels that are required to avoid unreasonable levels of annoyance in the real world, i.e., compliance levels, are highly variable from one situation to another (Miedema *et al.*, 2000; Ormerod *et al.,* 2003a), and may bear little resemblance to the planning criteria set by regulatory agencies.

It should be noted that the odour criteria referred to below are for application to assessments of complex odours (i.e., those caused by mixtures of odorous compounds). Simple odours associated with single compounds alone (e.g., hydrogen sulphide) are in many cases, where data are available, assessed by reference to mass concentration guidelines developed around odour threshold concentration data.

All states have now adopted the Australian/New Zealand Standard 4323.3:2001 *(Determination of odour concentration by dynamic olfactometry)*. All criteria quoted in the following summary are based on AS4323.3 odour data. In the absence of data that have been derived strictly in accordance with AS4323.3, due consideration should be given to the compatibility of the data to the criterion.

4.3.1 New South Wales

The draft NSW odour policy for stationary sources (NSW EPA, 2001) has been extensively applied, even though it is formally a draft document. The document is detailed and contains extensive technical explanatory material and guidance on application of the policy.

4.3.1.1 Default criteria

For new stationary sources, the policy sets out odour performance criteria of 2 to 7 ou (depending on affected population), averaged over the nose response time (taken to be approximately 1 second) and not to be exceeded for more than 1% of the time over a year. The application of the NSW odour policy involves taking into account the population affected by specified odour levels (see Table 4.1). The population-dependent approach recognises that in any sample of the general population there is a spread of odour sensitivities. In larger groups, the likelihood of there being very sensitive individuals increases and hence it is considered appropriate to reduce the risk of adverse effects by tightening the criteria.

Table 4.1: NSW EPA Odour Performance Criteria (NSW EPA, 2001)

Number of Affected People	Odour Performance Criteria (ou) $C_{99.0,\ 1\text{-second}}$ average
Urban Area (≥ 2000)	2.0
500 – 2000	3.0
125 - 500	4.0
30 – 125	5.0
10 – 30	6.0
Single Residence (≤ 2)	7.0

The NSW EPA approach assumes that a basic unit of time is the 'nose-response time', which effectively is assumed to be 1 second. The mean concentration is an hourly average, which is based on the usual basic time interval of calculation in plume dispersion models. A peak value is a statistical concept only, since random variations affect the values of rare, high-end concentrations and therefore a true peak value cannot be evaluated deterministically. Thus it is necessary to express the 'peak' value within the context of a probability of occurrence. The NSW EPA's proposed approach is to assess peak 1-second values that occur at a probability of 10^{-3} in a given hour.

The default criteria are not intended for application to the management of existing odour sources, and are for the assessment of new sources.

4.3.1.2 Alternative approach

The NSW odour policy document notes (after Table 3.1 of that document) that the values in Table 4.1 (above, this document) should be regarded as "interim criteria to be refined over time through experience and case studies. To allow for future updating of the odour performance criteria as new industry-specific research is completed, the acceptable procedure for developing future criteria is outlined in Technical Note 3.3. Before developing alternative criteria the EPA should be contacted to ensure the proposed work will be suitable for adoption in the policy and for broader use."

4.3.1.3 Conversion of NSW Criteria for this Study

Conversion of odour criteria from one percentile to another is strictly valid only when local meteorological factors are taken into account. Therefore, there is no accurate method of making 'default' or generalised conversions from one percentile to another when comparing odour criteria that are based on different percentiles. Hence, the only valid way of comparing the C_{99} NSW criteria with those from other jurisdictions is to take into account site-specific conditions. Clearly, however, the C_{99} value will always be lower than the equivalent $C_{99.5}$ or $C_{99.9}$ value.

The basic time unit used in dispersion models is one hour, i.e., inputs such as emission rates and meteorological parameters are expressed as 1-hour average values and accordingly the default for the output (odour concentration) is also the 1-hour average. When model results for shorter averaging times are required, the only available method is to apply a ratio to the hourly average value, based on empirical knowledge. For example, for averaging times between 3 minutes and 1 hour, a power law is widely used for this conversion. In the case of the NSW odour criteria, the averaging time is approximately 1 second and the conversion is based on theoretical considerations reported in the odour policy documentation. The conversion to 1-second values relies on peak-to-mean ratios, which vary according to source type, meteorological conditions and distance from the source. This is a complex procedure, especially when different source types are present at the same facility. For this study, the assumption is made that downwind impacts are dominated by wake-affected and low-level sources, for which an overall peak-to-mean ratio of 2.3 can be adopted as a first-order approximation, based on the policy guidelines. Hence, model predictions of odour impact for the Plant 3 and Plant 2 sites in NSW, although presented as 1-hour averages in this report, can be compared to the NSW odour criteria by multiplying them by 2.3 to yield approximate $C_{99\ 1\text{-sec}}$ values as given in Table 4.1. Alternatively, for guidance the criteria in Table 4.1 can be divided by 2.3 as in Table 4.2.

Table 4.2: Approximations to NSW EPA Odour Criteria Based on Peak-to-Mean Ratio of 2.3, for Comparison with Model Results for NSW Facilities in this Study

Population of Affected Community	Approximate Odour Performance Criteria $C_{99.0,\ 1\text{-hour}}$ (ou)
Urban Area (≥ 2000)	0.9
500 – 2000	1.3
125 - 500	1.7
30 – 125	2.2
10 – 30	2.6
Single Residence (≤ 2)	3.0

4.3.2 Western Australia

As with many odour policies, the WA odour policy (WA EPA, 2002) recognises the complexity of odour assessment and adopts a multi-faceted approach. The most conservative benchmark involves the use of so-called 'greenlight' criteria, which are very conservative. Any proposal that meets these criteria requires no further consideration with respect to odour. If the greenlight criteria cannot be met, then there is available an option to use an intensity-based approach.

4.3.2.1 Default or 'greenlight' approach

The WA EPA policy sets out planning criteria, which must both be met for a 'greenlight' approval, as:

- $C_{99.5,\ 3\text{-minute}}$ = 2 ou, and
- $C_{99.9,\ 3\text{-minute}}$ = 4 ou

4.3.2.2 Intensity-based approach

For proposals that do not meet the 'greenlight' criteria, an odour study may be conducted using odour intensity. The criterion using this approach is:

- odour concentration equivalent to an intensity level of 'distinct', averaged over 3 minutes, 99.5th percentile ($C_{99.5,\ 3\text{-min}}$).

This approach applies only to non-point sources. Application of this approach requires the establishment of an intensity-concentration relationship for the specific odour type.

The Western Australian guidance provides a specific intensity-concentration relationship for poultry operations. The “distinct” odour intensity category equates to a concentration of 7 ou. No pre-determined values are provided in the guidance document for other types of odour source.

4.3.3 Queensland

A draft odour policy is currently in preparation and is subject to the final stage of consultation. This process may lead to changes in the draft policy, so it is not wise to rely on details of the draft policy at the present time. The EPA expects to be released in a final form before the end of 2003.

The draft guideline “provides proponents, government agencies and the public generally with a procedure for assessing the likelihood of odour nuisance when proposals for new facilities, expansions of existing facilities, land developments and other planning schemes may result in sources of odour and sensitive land uses being placed in close proximity”.

The EPA expects to include odour criteria within the context of a ‘toolbox’ approach (similar to the New Zealand odour guidelines), which will set out different approaches for the assessment of existing vs new sources. Use will be made of current or similar experience with the industry, community attitudes, complaints and so on, and odour modelling will not be an automatic requirement in all cases.

4.3.3.1 Default criteria

A default approach will require the modelled odour concentrations at the “nearest existing or likely future off-site sensitive receptors**”** to be compared to the following criteria:

- $C_{99.5,\ 1\text{-hr}}$ = x ou, where x is yet to be determined and may be variable dependent on population or land use;
- for facilities that do not operate continuously, the 99.5th percentile must be applied to the actual hours of operation.

4.3.3.2 Intensity-based approach

Odour impacts from ‘non-point’ sources can be assessed using odour intensity-concentration relationships. The actual means of applying intensity is yet to be finalised.

4.3.3.3 Alternative odour criteria

The draft policy also allows the use of alternative odour criteria provided that they are well researched and relevant to the specific application. At present there are no details on what standards the EPA would apply to accepting alternative criteria.

4.3.4 South Australia

The South Australian EPA odour policy (SA EPA, 2003) includes odour concentration criteria for the quantitative assessment of odour impacts

The SA EPA odour criteria are population dependent. The predicted 3-minute average odour concentration, expressed as a 99.9th percentile, should not exceed the following levels at surrounding sensitive receptors, not including houses on the property of the development:

Table 4.3: South Australian Odour Performance Criteria

Number of people	**$C_{99.9,\ 3\text{-minute}}$ (ou)**
2000 or more	2
350 or more	4
60 or more	6
12 or more	8
Single residence (less than 12)	10

The SA EPA guidance notes that accurate odour modelling is highly dependent on the quality of the emission and meteorological data used. Consequently it is advised that proponents of any new development use the best data available and allow for a substantial margin of error in the odour modelling. The EPA advises that if an assessment predicts odour levels less than half of the criteria in Table 4.3, then the proponent can expect that the final development will remain within acceptable odour levels in most circumstances. If the predicted odour levels are double the criteria levels, then the whole concept of the development would probably need to be re-examined. Predicted odour levels between half and double the acceptable levels would warrant a general re-examination of the proposed odour control systems and of the modelling itself.

4.3.5 Victoria

The EPAV general criterion for odour assessment is:

$C_{99.9,\ 3\text{-minute}}$ = 1 ou, applied at and beyond the property boundary.

In practice many developments such as intensive livestock enterprises do not comply with this criterion, and the general EPAV procedure is to consider non-complying proposals on a risk assessment basis. In practice, a criterion commonly applied for these types of enterprise is:

$C_{99.9,\ 3\text{-minute}}$ = 5 ou.

4.3.6 Tasmania

A Draft Environment Protection Policy (Air Quality), dated September 2001, has been developed in Tasmania. The Draft Policy has been reviewed by an Environment Protection Policy Review Panel and is expected to be finalised in the near future.

The draft policy states that "if a regulatory authority is satisfied that odour from a source is causing or is likely to cause an environmental nuisance or material environmental harm, an atmospheric dispersion calculation shall be performed to ensure that the maximum ("worst case") ground level concentration does not exceed the concentration criteria" contained in Table 4.4.

Table 4.4: Draft Tasmanian Odour Criteria (Schedule 3, Draft Air EPP)

Type	Criteria	Averaging period	Percentile
Known Pollutant	See Schedule 2 of EPP	See Schedule 2 of EPP	99.9[1]
Unknown Mixture	2 odour units	1 hour	99.5[2]

1. The 'known pollutant' criteria for odorous properties are confined in the draft EPP to xylene.
2. For odorous mixtures, the criterion is $C_{99.5\ 1hr}$ = 2 ou. This is to be determined by modelling and applies at or beyond the boundary of a facility (whichever has the higher impact). In cases where local high-quality meteorological and emissions data are not available, the maximum (100th percentile) concentration modelled at or beyond the boundary applies.

4.4 Industry-specific Criteria

4.4.1 Planning

One of the difficulties facing regulators and industry in relation to odour criteria is that there are clear signals that different types of odour warrant different numerical odour criteria to take into account the varying potential to cause annoyance. Hence, the 'one size fits all' approach implied in the various criteria adopted in Australian jurisdictions and elsewhere runs counter to common knowledge about odour effects. Some odour policies attempt to deal with this problem by allowing industry-specific or facility-specific criteria based on either specific industry studies (e.g., poultry guidelines in Western Australia), or by using tools such as the odour intensity-concentration relationship (e.g., WA and draft Queensland policies). In other jurisdictions, such as The Netherlands, differing odour criteria have been developed for a range of industries and receptor situations.

In Australia, recent developments in the pork industry have led to an attempt to devise suitable odour criteria for planning and assessment of intensive pig farming enterprises. In that case, there is also a move towards use of the 98^{th} percentile as an indicator of odour impacts, in preference to the higher percentiles currently favoured in existing Australian odour policies. This possible shift, subject to the outcome of a current study, is consistent with recent developments in Europe and recognises that higher percentiles may be less stable indicators of odour impacts, due partly to the possibility of ‘rogue’ meteorological data influencing the results as the percentile value increases. Also, very high percentiles, which by definition occur only very infrequently, may not be good indicators of the more frequent impacts that are likely to cause chronic annoyance.

In light of these factors, the development of odour criteria specifically for the meat industry would appear to be warranted.

4.4.2 Compliance

Apart from planning criteria, a sensible approach to identifying appropriate compliance levels is important. Since there are many variable factors that influence the odour dose-response for individuals and communities (e.g., van Harreveld, 2002; Miedema *et al*., 2000; Ormerod *et al*., 2003a), the best way of determining compliance levels in a robust way is to focus on specific industries or indeed specific facilities, using a combination of methods such as community odour surveys, complaints analysis, field odour assessments, emissions measurement and modelling (e.g., Ormerod *et al*., 2002). For this study, a limited set of these data sources is available.

5 METEOROLOGY

Wind speed and direction are two of the most important meteorological parameters that influence the dispersion of odours. A summary of wind conditions provides basic information that can explain the likely patterns of odour plume impact.

Odours are generally less effectively dispersed or diluted by the atmosphere when the wind speed is low. Hence, periods of light winds are those generally most likely to result in greater impacts downwind of the source.

The level of turbulence in the atmosphere also affects plume dispersion. When turbulence is stronger, the random motions that occur cause plumes to more quickly spread, thus diluting the odour more effectively. Conversely, when there is very little turbulence, plume spread and dilution are restricted.

Typically, turbulence levels are greatest during the daytime and lowest at night and in the early morning. Very low levels of turbulence occur when the air is stable. These conditions, which are marked by a temperature inversion (temperature increasing with height above the ground), occur when the sky is relatively free of cloud at night. The combination of very light winds and low turbulence, which typically occurs on still clear nights, is the least favourable set of conditions for plume dispersion.

Meteorological data has been collected from on-site weather stations for each of the three locations for use in dispersion modelling. Appendix A contains wind roses for each of the three sites.

6 METHODOLOGY

The technical aspects of this study have involved the use of several tools for gathering or processing the necessary data. These include:

- dispersion modelling to mathematically simulate the dispersion of odour from sources that have been quantified;
- measurements by The Odour Unit of major odour sources, to estimate emission rates that are required for modelling;
- use of a field technique using odour intensity to estimate downwind odour concentrations for comparison model results;
- evaluation of model results against available information on complaints, annoyance or other indicators of odour impact (e.g., odour policy criteria).

6.1 Dispersion Modelling

Various plume dispersion models are in common use in Australia. Traditionally, simple Gaussian plume models such as Ausplume have been used for the assessment of odours and other pollutants. However, these simple models have a variety of limitations, which can be very important when dealing with odour in particular. For example, the Gaussian plume models are least accurate under conditions of very light winds and stable atmospheric conditions, which are usually the most critical conditions for odour impact.

In recent years, new developments in modelling have given rise to several more sophisticated, three-dimensional models being available for routine use. These include TAPM and CALPUFF, which are described below. Such models are able to deal much more realistically with complex meteorological conditions, provided that the input data describing the meteorology are reasonably accurate. In principle, models such as CALPUFF provide a much better basis for modelling odour impacts. However, practical issues such as the availability of good quality meteorological data limit its optimal use. A significant benefit in dealing with this problem is the use of prognostic meteorological models that can simulate meteorological conditions for locations where measurements are not available, or are not adequately detailed to use directly in models such as CALPUFF. Examples of such prognostic models include TAPM and MM5.

The Air Pollution Model, or TAPM, is a three dimensional meteorological and air pollution model produced by the CSIRO Division of Atmospheric Research. Detailed description of the TAPM model is provided elsewhere, (Hurley 1999). Briefly, TAPM solves the fundamental fluid dynamics and scalar transport equations to predict meteorology and pollutant concentrations. It consists of coupled prognostic meteorological and air pollution concentration components, eliminating the need to have site-specific meteorological observations. The model predicts airflow important to local scale air pollution, such as sea breezes and terrain induced flows, against a background of larger scale meteorology provided by synoptic analyses.

TAPM incorporates the following standard databases for input to its computations:

- Gridded database of terrain heights on a longitude/latitude grid of 30 second grid spacing, (approximately 1 km). Fore this study, however, more detailed terrain data at 9 second resolution has been obtained from the Auslig digital terrain database for Australia.
- Australian vegetation and soil type data at 3 minute grid spacing, (approximately 5 km).
- Rand's global long term monthly mean sea-surface temperatures on a longitude/latitude grid at 1 degree grid spacing, (approximately 100 km).
- Six-hourly synoptic scale analyses on a longitude/latitude grid at 0.75-degree grid spacing, (approximately 75 km), derived from the LAPS analysis data from the Bureau of Meteorology.

The CALMET meteorological model is the meteorological processor for the CALPUFF modelling system. It requires input of a number of meteorological parameters, which are provided by data generated by TAPM and supplemented by observational data. The meteorological fields generated by CALMET are then input directly into the CALPUFF model.

CALPUFF is a multi-layer, multi-species non-steady state puff dispersion model that can simulate the effects of time- and space-varying meteorological conditions on pollutant transport, transformation and removal. The model contains algorithms for near-source effects such as building downwash, partial plume penetration, sub-grid scale interactions as well as longer-range effects such as pollutant removal, chemical transformation, vertical wind shear and coastal interaction effects. The model employs dispersion equations based on a Gaussian distribution of pollutants across the puff and takes into account the complex arrangement of emissions from point, area, volume, and line sources.

CALPUFF requires the following input data:

- Three-dimensional meteorological data output from CALMET;
- Land use data (used to parameterise surface roughness and other aspects relevant to plume dispersion);
- Emission source locations and physical characteristics;
- Emission rates from all individual sources, and
- Building layout and dimensions.

6.2 Odour Intensity Field Observations

Odour intensity has been adopted as the basis for recording semi-quantitative odour data in the field for the purpose of analysis and assessment. The method developed for the project permits quantification of ambient odour levels at concentrations at least 100 times lower than is possible using dynamic olfactometry. This allows validation of odour dispersion models, a process previously not possible. However, a thorough validation process requires many data points (preferably at least 50), which is beyond the scope of this study. Hence, the data obtained by this method in this study are useful for gross checking of model results, and do not permit detailed validation.

Odour intensity is a subjective concept. However, to standardise the odour logging and analysis approach as far as possible, two major steps have been taken:

- Adoption of a standard scale for describing odour intensity, as detailed in the German Standard VDI 3882 (I) which relates to odour measurement; and
- Assessment of the odour intensity-concentration relationship for odour emitted from the main stack, as an adjunct to the normal dynamic olfactometry procedure.

The odour intensity scale is summarised in Table 6.1.

Table 6.1: **German VDI 3882 Odour Intensity Scale**

Odour intensity	***Intensity level I***
Extremely strong	6
Very strong	5
Strong	4
Distinct	3
Weak	2
Very weak	1
Not perceptible	0

Observations of odour intensity in the field for this project are based on the approach detailed in The German VDI 3940 (“Determination of Odorants in Ambient Air by Field Inspection”). Observations were made at various locations downwind of the plant. The observed odour intensity measurements were used as a basis for estimating mean and peak odour concentrations and peak-to-mean ratios. Further information can be found in Appendix B.

The derivation and use of this method for field odour evaluations has been described in recent papers (e.g., Ormerod *et al*., 2002).

7 RESULTS PART 1: ODOUR MEASUREMENT, EMISSION RATES AND FIELD OBSERVATION

7.1 Odour Emission Rates

A series of odour samples was collected by The Odour Unit (TOU) at the three study sites, focussing on the major odour sources as determined from both observation and previous work at these sites by TOU.

Odour emissions from rendering facilities, like many other types of source, are often complex and difficult to sample and to convert to emission rates with a high degree of confidence. Because odour measurement is relatively expensive (in that most studies allow only a snapshot view of odour emissions, with few samples per source) and odour emissions are complex and variable, odour emission rates derived for modelling are typically a significant source of uncertainty. In this case, Table 7.1 lists the emission rates derived by TOU for use in the modelling component of this study. There will inevitably be variations in emissions around the values given in Table 7.1, and there is uncertainty arising from the practical limitations of sampling odour streams and calculating (where relevant) volumetric airflow rates in complex situations. Hence, the emission rates should be regarded as approximate only. However, TOU's experience with these sites has been valuable in ensuring that the data are the best available under the circumstances.

Table 7.1: Odour Emission Rates (OER) used in Dispersion Modelling

Source	Total OER (ou.m³/s)
Plant 1	
Boiler	570
Biofilter	149 850
Dispersion Stack 1	418 600
Dispersion Stack 2	481 600
Plant 2	
Rendering Building	109 000
DAF	29 615
Contra Shear	18 000
Cyclone	863
Tallow Boiling	63 000
Plant 3	
Rendering Building	4 600
Biofilter	25 900
WW Receivable Pit	7 161
Holding Pen (kill floor)	38 050
Holding Pen (main)	2 500

Note that the emission rate alone does not determine the level of ground level impact of an odour source. A key additional factor is the effective plume height, which is a function of both the release height and of the plume's buoyancy. For example, a buoyant (hot) plume released from a tall stack will have much less impact than a source with a similar emission rate that is released at ambient temperature near ground level. The buoyant stack emission will lead to an effective plume height that is well above ground level, helping to reduce its impact. However, atmospheric turbulence will eventually mix plume material to the ground, regardless of the plume height. With an elevated plume, this process takes longer and the plume is consequently more diluted by the time it reaches the ground.

It is noted that in Table 7.1 the emissions from Plant 1 and Plant 2 are substantially higher than those from Plant 3, and that unlike the other two facilities, over 50% of odour emissions from Plant 3 are from holding pens. For this reason, it was considered that holding pen emissions were significant and ought to be considered in the assessment for Plant 3.

7.2 Odour Observations

7.2.1 Mean odour concentrations

Analysis of odour intensity data allows estimation of mean odour concentration, which can be compared to odour modelling predictions. The comparison is presented in section 0.

An observation is typically based on a 30-minute series of odour intensity samples taken every 10 seconds by a trained observer. The method is an adaptation of the German VDI 3940 standard, and uses the intensity scale of VDI 3882. Mean odour concentrations for each observation period are derived from the relationship between odour intensity and odour concentration, determined initially in the laboratory as an extension of the routine determination of odour concentration by dynamic olfactometry.

The calculation of mean odour concentration involves converting the odour intensity data to odour concentration data. Because there is a range of possible concentration values corresponding to each intensity value, each observation time series is simulated 100 times using a Monte Carlo technique to create a cluster of possible concentration results corresponding to the original intensity observations. Details are given in Appendix B. This was done for each odour observation performed for this study and the results are detailed in Table 7.2. These data have been used for simple comparisons with model predictions of odour at the same times and locations as the field observations. Note that the mean odour concentrations are all much less than the practical concentration threshold for dynamic olfactometry, which is generally regarded as around 20-30 ou.

Table 7.2: Estimated mean odour concentrations from observed odour intensity observations

Observation	Mean odour concentration (ou)			Maximum odour concentration (ou)	Maximum: Mean (b)
Site & No.	Max. Estimate (a)	Min. Estimate (a)	Median Estimate (a)	Average Estimate (a)	Average Estimate (a)
Plant 1 1	1.75	1.31	1.54	31.7	20.4
Plant 1 2	0.33	0.20	0.27	5.3	19.5
Plant 1 3	0.91	0.61	0.73	19.8	26.6
Plant 1 4	2.73	2.24	2.47	27.2	10.9
PLANT 3 C1	0.44	0.29	0.38	2.0	5.2
PLANT 3 C2	0.18	0.10	0.14	1.5	10.6
PLANT 3 1145	0.61	0.41	0.48	5.0	10.2
PLANT 3 1320	0.33	0.24	0.28	1.7	6.1
Plant 2 1	0.38	0.31	0.33	2.0	5.9
Plant 2 2	1.66	1.17	1.42	14.8	10.4

a. Estimates are based on 100 simulations that estimate odour concentration (ou) from field observations of odour intensity recorded on the VDI 3882 scale.
b. Maximum:mean is the ratio of the observed maximum to the observed mean odour concentration, and is an estimate of peak:mean ratio. See Appendix B for further explanation.

8 RESULTS PART 2: MODEL RESULTS

8.1 Performance of Dispersion Model

8.1.1 Comparison of Observed and Modelled Concentrations

A comparison between the predicted model results and field odour observations can be made in order to validate the results of odour dispersion modelling, or this case to gain some level of confidence in the general magnitudes of the emission data. Any comparison of modelled and observed concentrations must take into account the uncertainty inherent in both sets of data. The uncertainty in the estimated odour concentrations based on intensity observations can be expressed simply by the range of estimated mean concentrations, as shown in Table 8.1.

Models predict so-called ensemble mean concentrations. For a given set of meteorological conditions, averaged over 1 hour, the resulting ground level concentration predicted by the model is the average that would occur under those conditions (assuming the model is accurate). In any specific hour, however, turbulence in the atmosphere will cause variations in actual concentrations, so that even a “perfect” model will not capture these random variations. Hence, when the model predicts a certain result, the actual concentrations in the field under the same conditions may differ significantly from the model result. Only by gathering data from many similar situations will the model result and the average results from the real world coincide. Whether an individual observation (e.g., of 30-minute averaged odour concentrations) matches the model prediction for that event is strongly influenced by random factors. Any individual real-world result may differ from the model by at least a factor of two due to turbulence-based variability (Stein and Wyngaard, 2001). Hence, a factor of two around the model prediction is a fair indication of the range of values one might expect when comparing the model result with an actual measurement. (It is important to note, however, that when model results are considered over long periods, such as a year, the effects of the individual hourly variations between model and real world tend to cancel out).

Table 8.1: Comparison of Odour Concentrations (ou) based on Observations and Dispersion Modelling

Site & No.	Observation Concentration Range (ou)	Modelled Concentration Range (ou)[1]
Plant 1 1	1.31 – 1.75	6.6 – 26.6
Plant 1 2	0.2 – 0.33	6.4 – 25.6
Plant 1 3	0.61 – 0.91	6.6 – 26.6
Plant 1 4	2.24 – 2.73	6.6 – 26.6
PLANT 3 C1	0.29 – 0.44	6.9 - 27.6
PLANT 3 C2	0.10 – 0.18	6.8 – 27.2
PLANT 3 1145	0.41 – 0.61	0.7 – 2.8
PLANT 3 1320	0.24 – 0.33	0.4 – 1.6
Plant 2 1	0.31 – 0.38	5 – 20
Plant 2 2	1.17 – 1.66	5 – 20

1. The ranges in modelled concentrations reflect the factor of two around the mean, as discussed above.

The modelled odour concentration ranges listed above are predominantly above the observed levels. Aside from the expected variation between real world and modelled predictions (as discussed above), the proximity of odour observations to the odour source appears to be a source of inaccuracy. The most important factor behind this inaccuracy may be the thermal buoyancy of the plume, which can be important even in situations where the plume temperature is only marginally higher than the ambient temperature (Ormerod *et al.*, 2003b).

8.1.2 Importance of thermal plume buoyancy in modelling

Ground level concentrations (glc) of odour (or any other pollutant) predicted by dispersion modelling can be extremely sensitive to thermal plume buoyancy. This is of particular importance when modelling area or volume source emissions, where the release height is close to ground level and therefore the effective plume height (taking into account plume rise due to buoyancy) may be substantially different from the non-buoyant plume height. This difference can critically affect ground level impacts particularly at close range to the source (i.e., in the near field).

An analysis of the sensitivity of glc's to plume buoyancy was made using the Plant 1 biofilter as an example. Figure 8.1 to 8.4 show ground level concentrations resulting from biofilter emissions at temperatures of 40°C (actual measured operating temperature), 30°C, 20°C and 10°C. All other modelling parameters remain constant. The results displayed are based on a full year of modelling, and show the 99.5th percentile of the 1-hour average concentrations for the year (i.e., the $C_{99.5\ 1\text{-}hr}$ values).

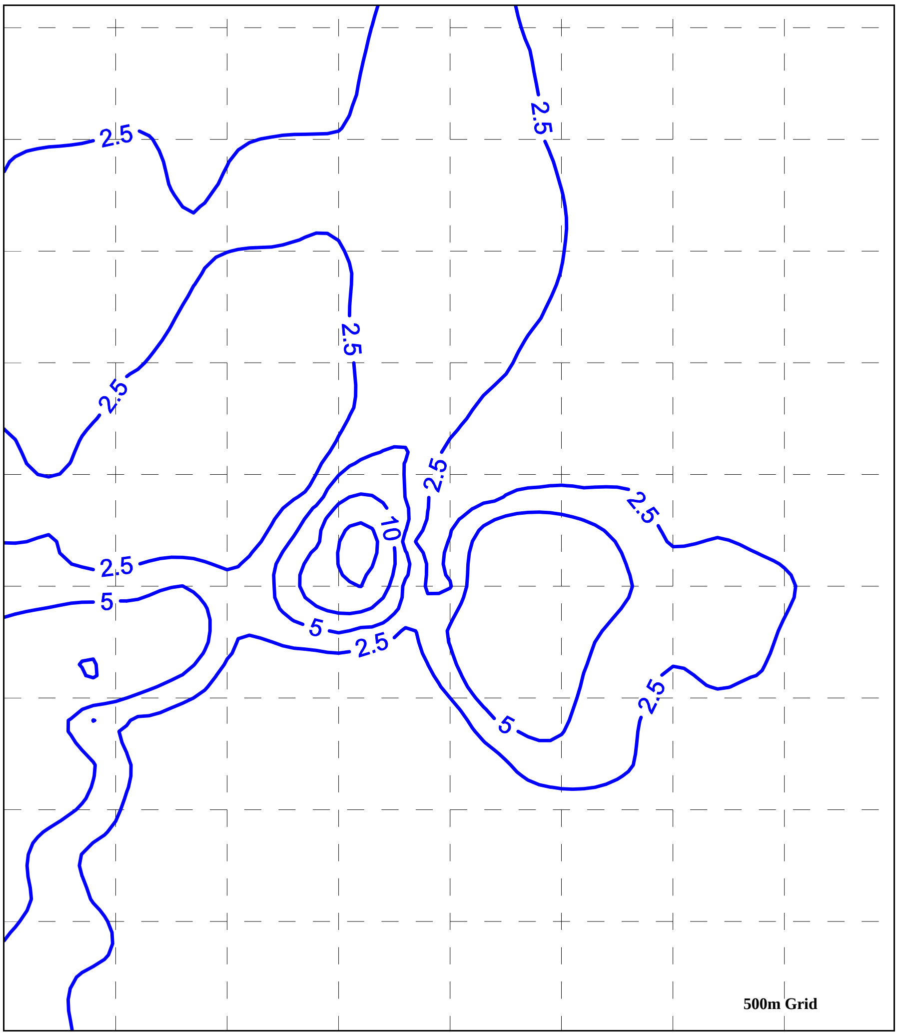

Figure 8.1: $C_{99.5\ 1\text{-}hr}$ Odour Concentration (ou) Resulting from 40°C Biofilter Emissions

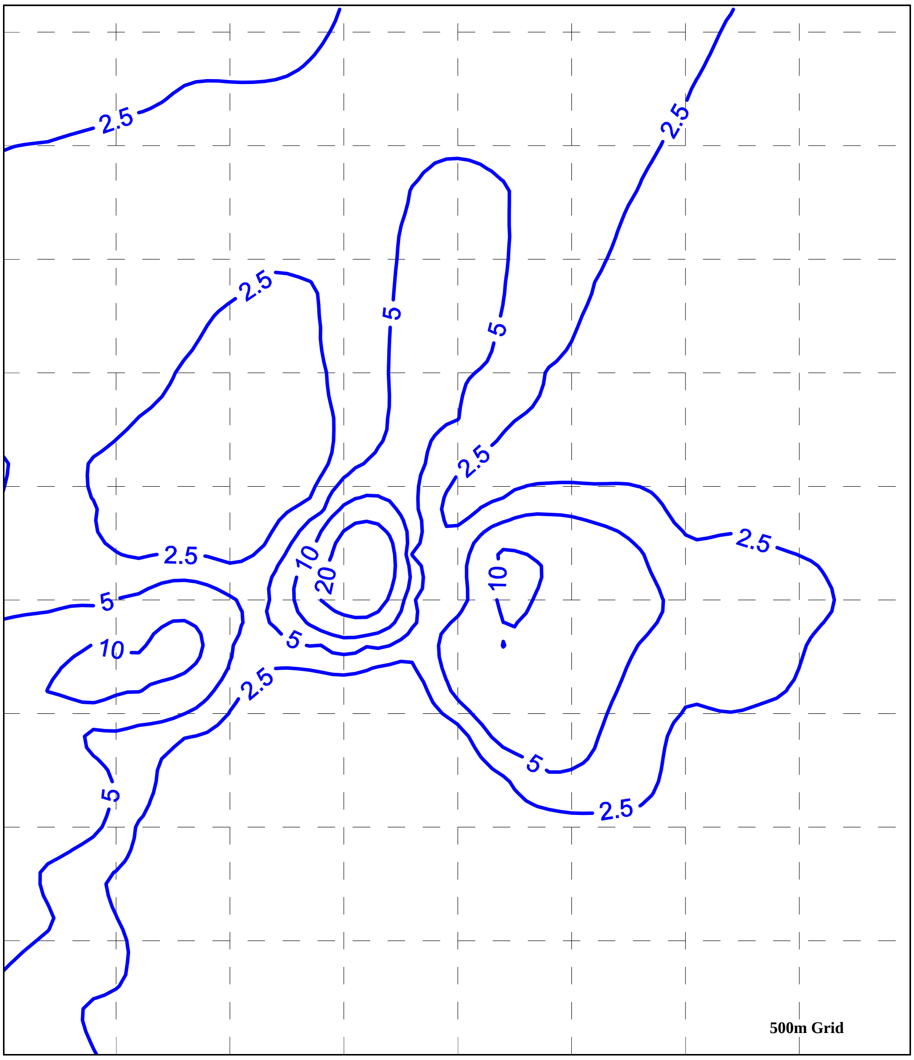

Figure 8.2: $C_{99.5\ 1\text{-}hr}$ Odour Concentration (ou) Resulting from 30°C Biofilter Emissions

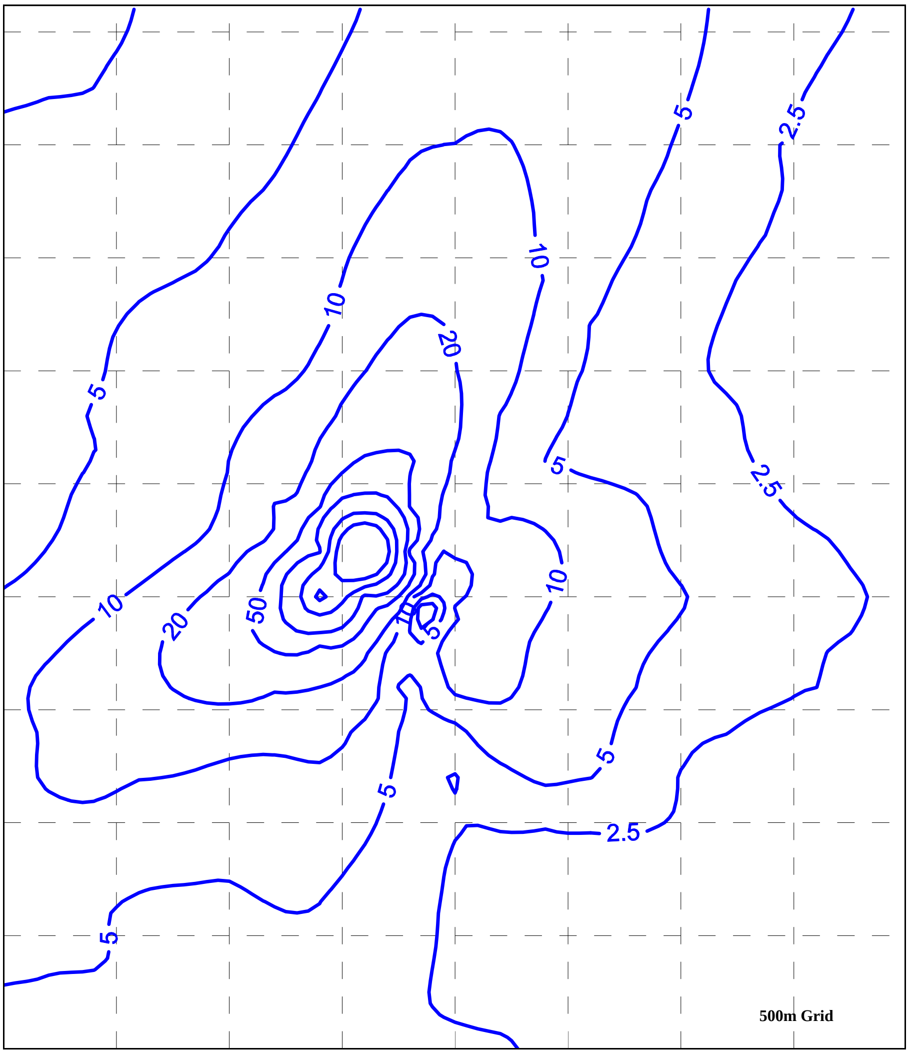

Figure 8.3: $C_{99.5\ 1\text{-hr}}$ Odour Concentration (ou) Resulting from 20°C Biofilter Emissions

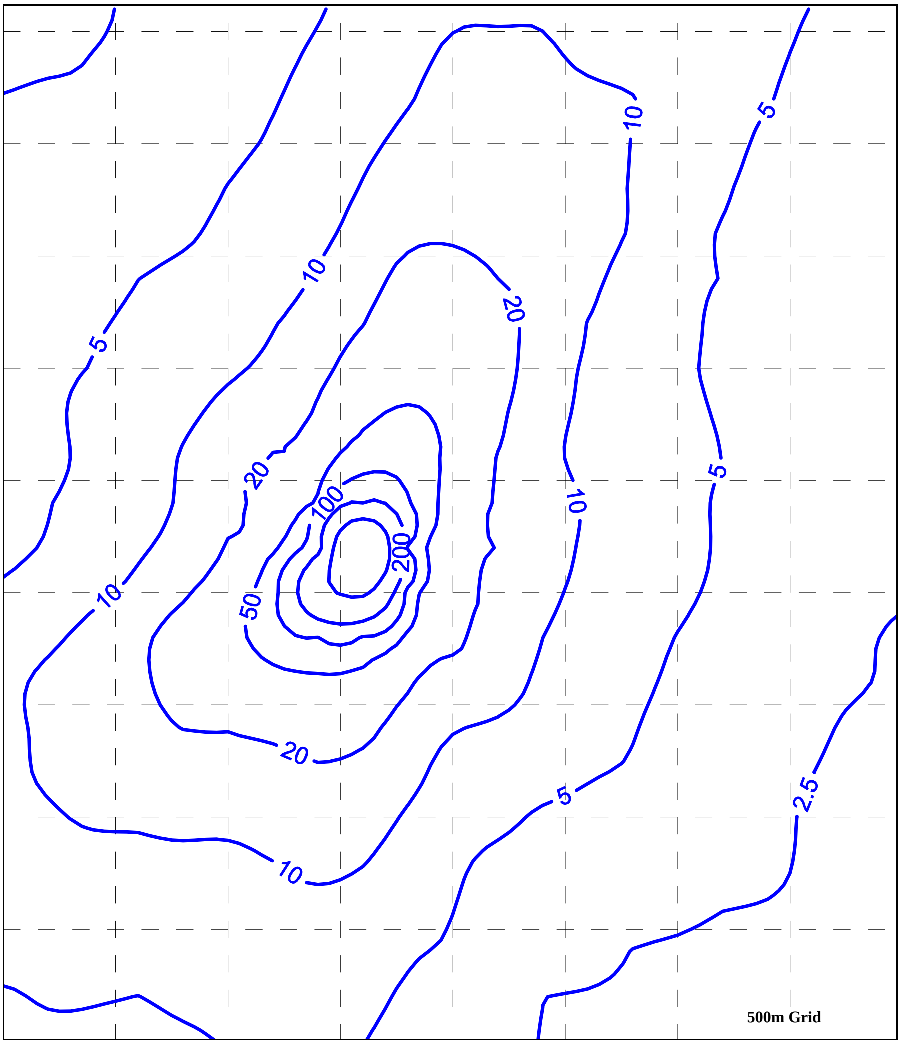

Figure 8.4: $C_{99.5\ 1\text{-}hr}$ Odour Concentration (ou) Resulting from 10°C Biofilter Emissions

Comparison of Figure 8.1 to 8.4 clearly show the importance of incorporating plume buoyancy into area and volume source emissions. However, to date it appears that there has been little close attention to this detail in many odour studies, and therefore some focus on this issue would appear to be warranted (Ormerod *et al*., 2003b). Also, modelling results using the same emissions data could vary substantially depending on the assumptions made about plume buoyancy. This has implications for assessment and analysis of impacts.

It should be noted that model setup for the simulation of buoyant area or volume sources has involved the use of the point source configuration, with the fitting of parameters to achieve the correct balance between plume rise due to momentum and thermal buoyancy.

Finally, the results indicate that there may be some limitations to the use of the odour intensity field observations in the near field downwind of buoyant low level sources, unless the buoyancy can be accurately characterised in the model. At present, this remains an area requiring further data before it can be done with confidence.

8.1.3 Plume mapping by intensity observation

Field observations can be used for mapping of a plume path, by taking multiple observations at points a significant distance from the source (i.e. in the far field). The results of the observations can then be compared to dispersion model predictions for the same meteorological conditions. Intensity observation plume mapping was conducted for Plant 2 over a period of ½ hour on 7 August 2002. The results appear in Table 8.2, ands the odour intensity–concentration relationship for rendering odours is shown in Figure 8.5. Note that the character of the odour detected indicated two distinct source types: rendering odours and the urine-like smell from holding yards (livestock).

Table 8.2: Plume Mapping Intensity Observations

Observation	Intensity	Corresponding Odour Concentration (ou)[1]	Odour Character
A	1	<1	Intermittent, very weak rendering
B	1-2	<1.5	Intermittent
C	1	<1	Rendering and livestock
F	2	1.5	Rendering
C	1	<1	Fairly constant rendering
H	0	0	
I	1-1.5	<1	Fairly constant rendering
L	2	1.5	

1 Refer to Figure 8.5

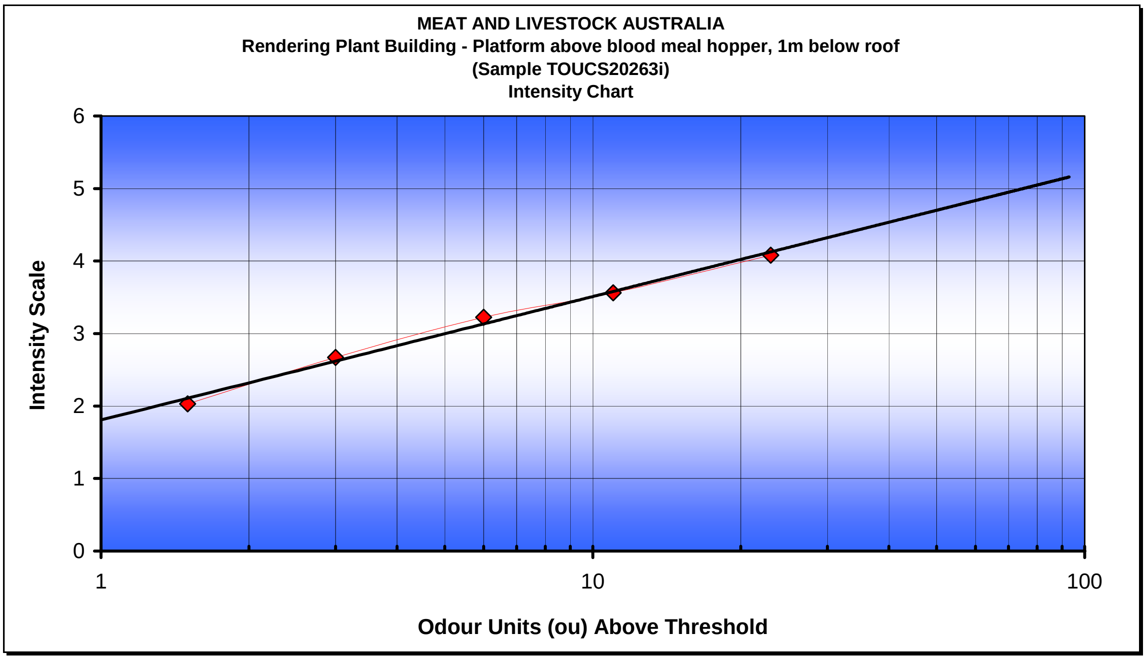

Figure 8.5: Plant 2 Rendering Odour Intensity Chart

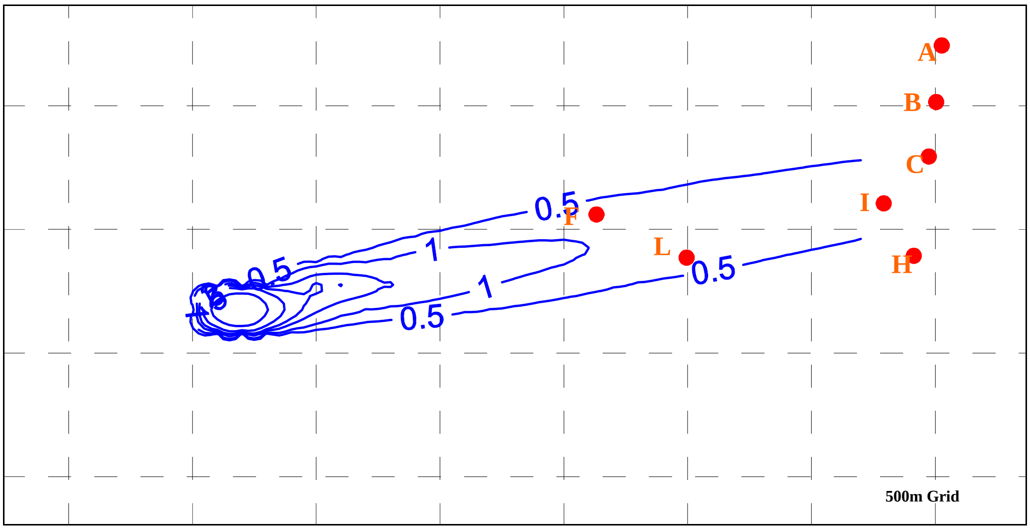

Figure 8.6: Observation Locations and Plume Concentration (ou, 1-hr average) Predicted by Dispersion Model

As discussed in Section 8.1, individual real world observations may differ from mathematical modelling by at least a factor of 2. Bearing this in mind, the modelling results shown in Figure 8.6, compare well with the plume mapping odour intensity observations. This suggests that the mathematical modelling used for this study provides a good representation of real world odour impacts, at least in the far field.

8.2 Dispersion Modelling Results

The dispersion modelling results shown in this section reflect the current draft guideline criteria (as discussed in Section 4) for each respective site. Also included are 98th percentile levels ($C_{98\ 1\text{-hr}}$). An odour workshop conducted by Australian Pork Limited (APL) in November 2002 concluded that the C_{98} values may be a better indicator of odour impact than the higher percentiles currently used in Australia. A report commissioned by APL (Ormerod, 2003) showed that, despite limited available data, use of percentiles between 98 and 99 was likely to be most suitable for odour assessment.

The C_{98} is used extensively in Europe and has the advantage of being less sensitive to extremes and errors in the meteorological data. In order to achieve the same level of protection against odour nuisance as is achieved by using a higher percentile, the C_{98} requires the adoption of a different, lower odour concentration. A recent study of an industrial odour issue included an extensive odour annoyance survey in Gladstone (central Queensland), with 524 respondents. Correlation of the annoyance levels and modelled odour concentrations indicated that the C_{98} was best correlated with reported annoyance (PAE, 2002).

In Figure 8.7 to Figure 8.12, which display dispersion modelling results, areas around the subject facilities from which complaints have been made are marked with red ellipses.

8.2.1 Plant 1

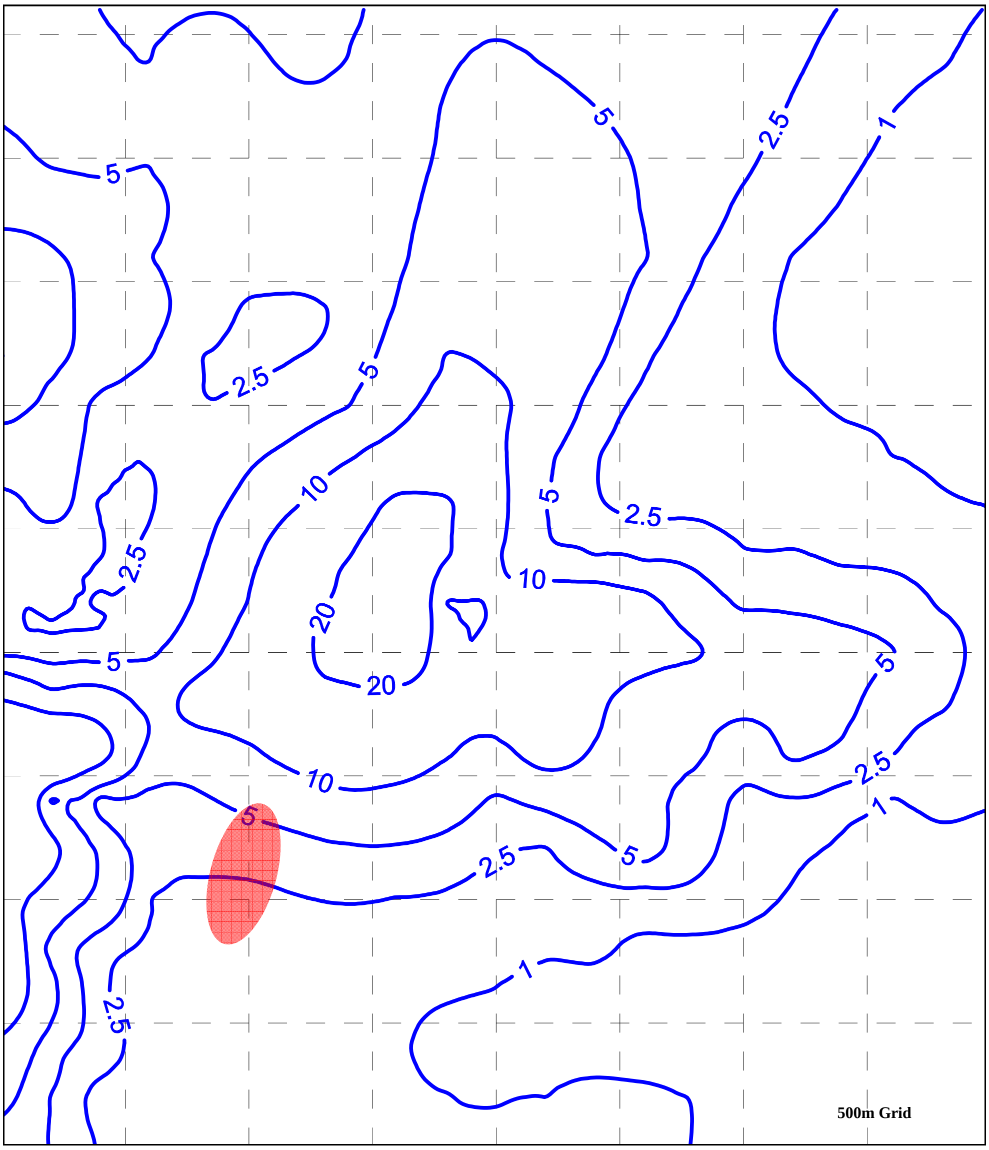

Figure 8.7: $C_{99.5\ 1\text{-hr}}$ Odour Concentration (ou) – Plant 1 Rendering

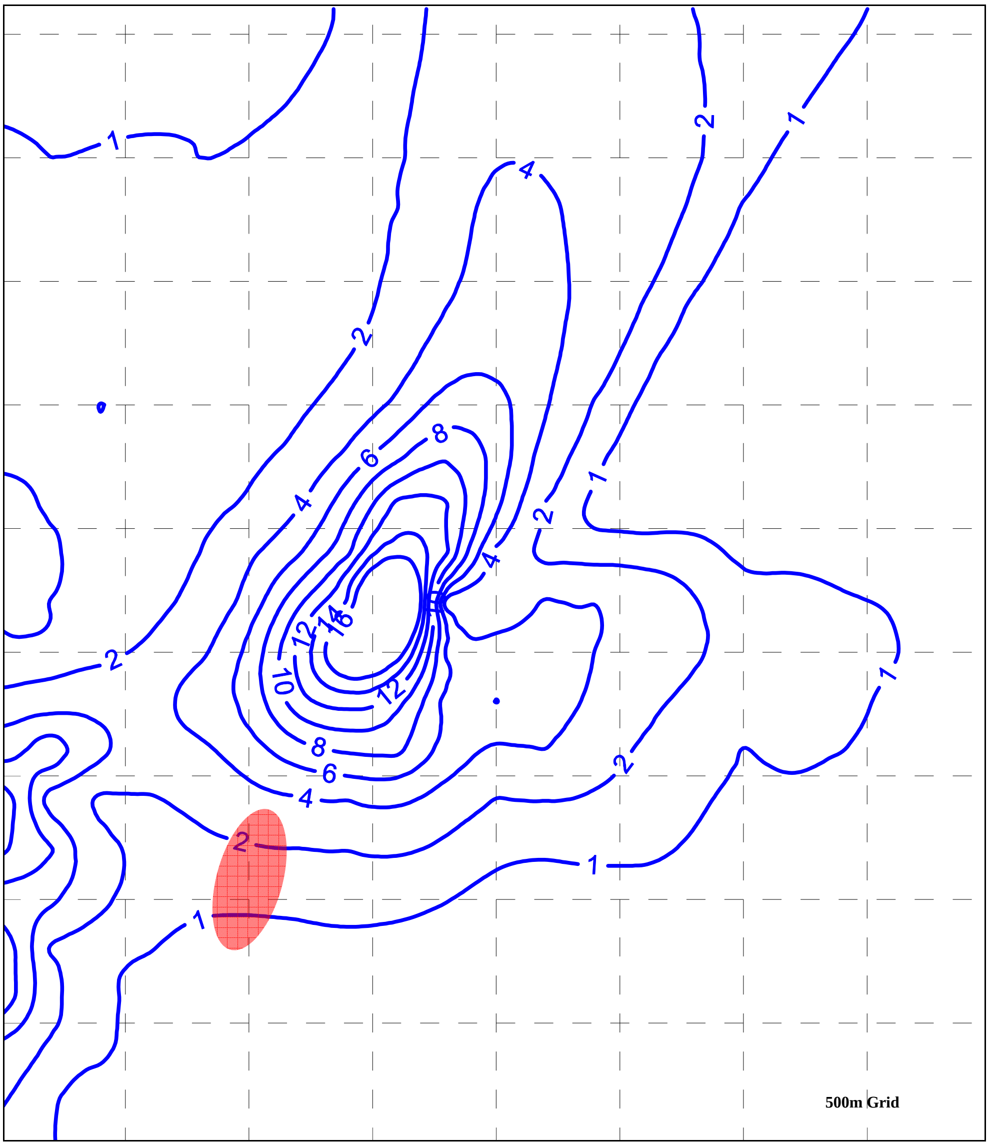

Figure 8.8: $C_{98\ 1\text{-hr}}$ Odour Concentration (ou) – Plant 1 Rendering

8.2.2 Plant 2

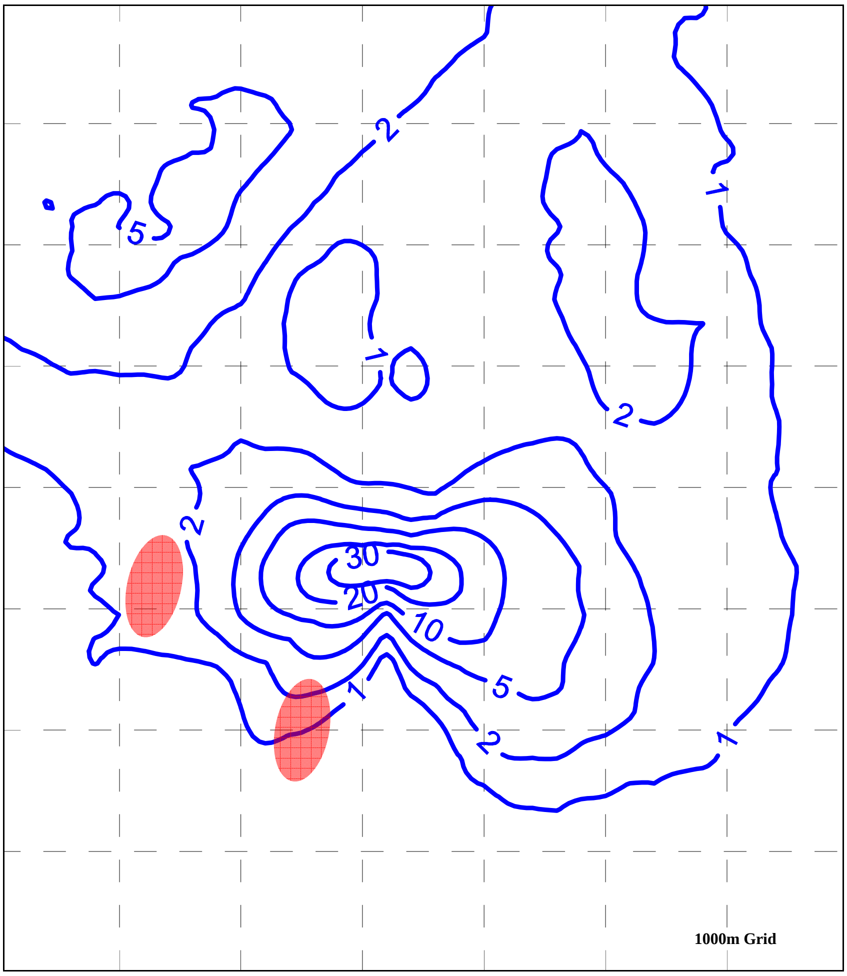

Figure 8.9: $C_{99\ 1\text{-hr}}$ Odour Concentration (ou) – Plant 2 Rendering

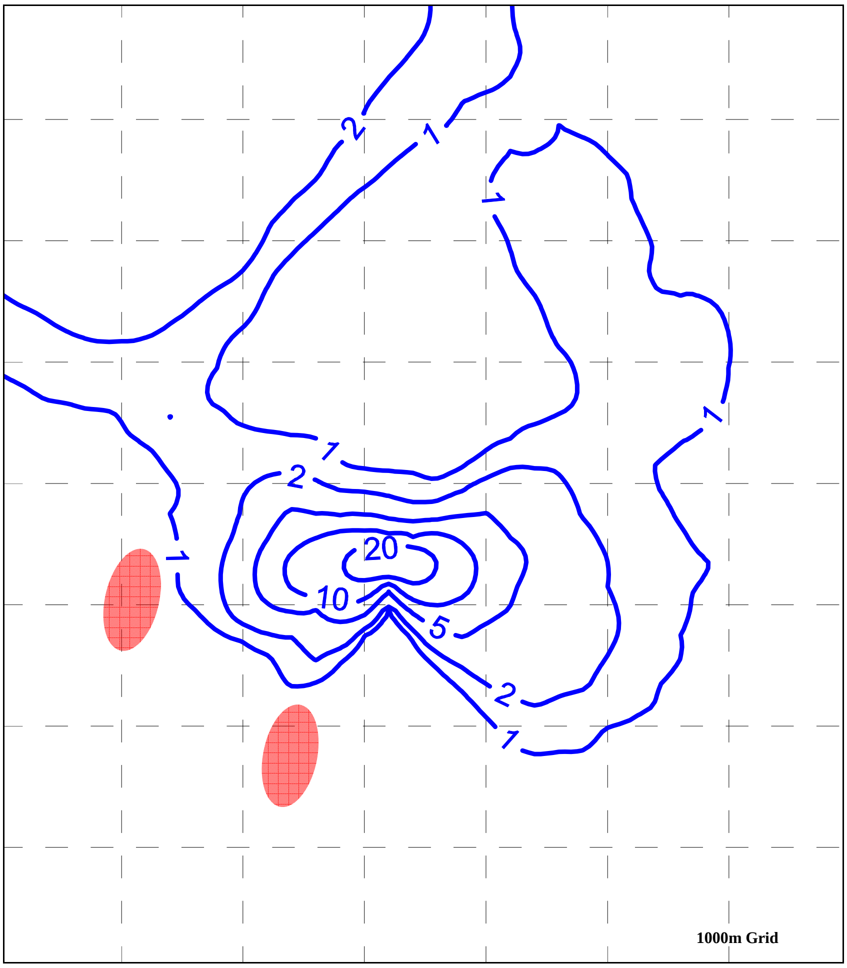

Figure 8.10: $C_{98\ 1\text{-}hr}$ Odour Concentration (ou) – Plant 2 Rendering

8.3.2 Plant 3

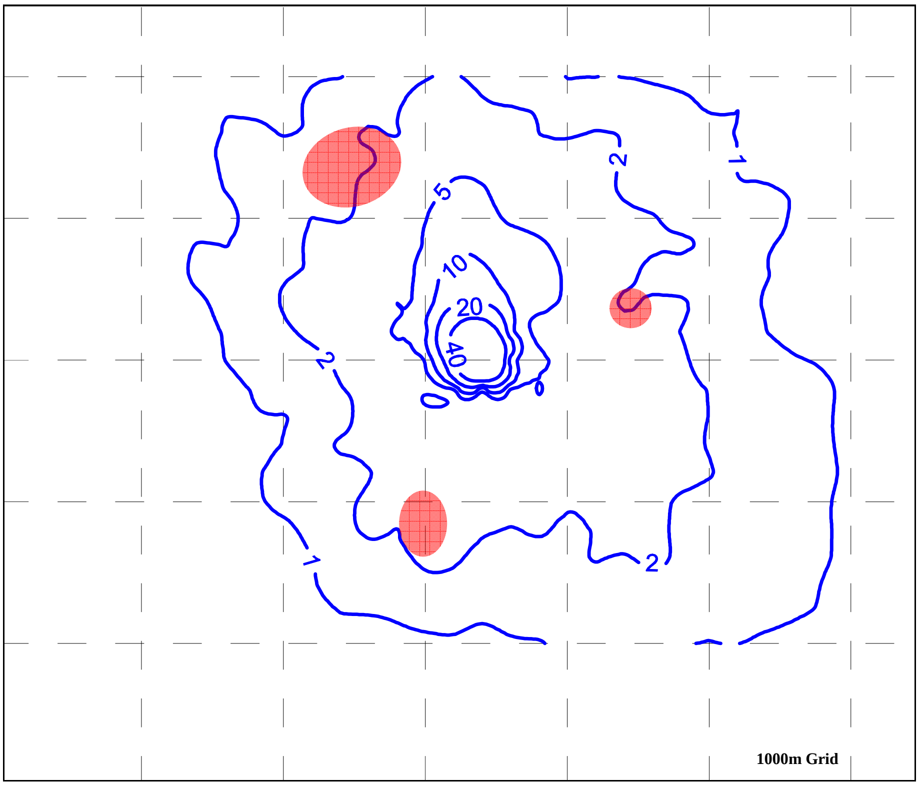

Figure 8.11: $C_{99\ 1\text{-}hr}$ Odour Concentration (ou) – Plant 3 Rendering and Holding Pens

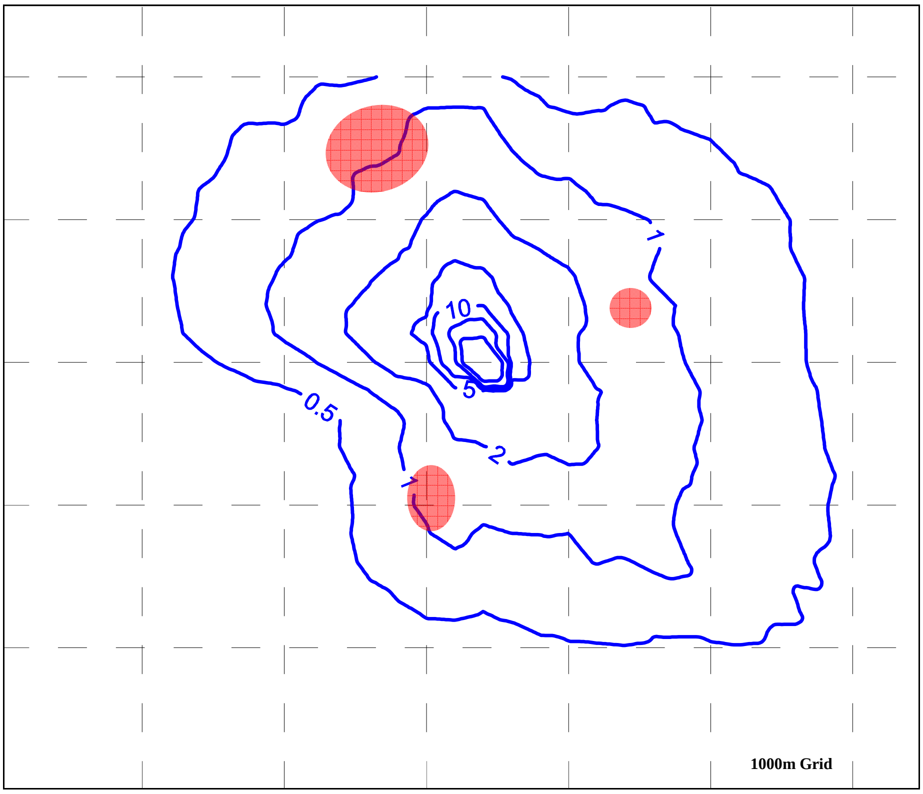

Figure 8.12: $C_{98\ 1\text{-hr}}$ Odour Concentration (ou) – Plant 3 Rendering and Holding Pens

9 DISCUSSION

The model results displayed in section 8 are discussed in this section.

9.1 Plant 1

The modelled odour concentrations in Figure 8.7 and Figure 8.8 show that the area in which residents have complained about odours coincides with $C_{99.5\ 1\text{-hr}}$ values of approximately 2 - 6 ou, and $C_{98\ 1\text{-hr}}$ values of about 1 - 3 ou. As indicated in section 8.1, the modelled values are sensitive to assumptions about plume buoyancy. In addition, the on-site meteorological data for the Plant 1 site indicate strong topographic influences, with preferential channelling of the flow along the north-south valley axis in that area. Away from the immediate vicinity of the on-site weather station, local flows may differ significantly from the measured data, and the success of the model in simulating those flows is somewhat uncertain. Hence, the model results should be regarded as indicative rather than highly accurate.

In arriving at a suitable odour criterion for this site, consideration also needs to be given to the relatively small population in the surrounding area, and the lack of detailed quantitative data on complaints and the circumstances under which they have occurred.

Notwithstanding these issues, the results would suggest that the $C_{99.5\ 1\text{-hr}}$ value should not exceed approximately 2 ou, or a little less, and the $C_{98\ 1\text{-hr}}$ should be about half that value. (Note that the ratio between these percentiles is site-specific, but often it has a value of about 2 – see section 4.2).

9.2 Plant 2

Figure 8.9 and Figure 8.10 show two areas in which some odour complaints have occurred. The area to the west of the plant is on a hill, and the impact of buoyant emissions on this area is significant, again highlighting the importance and sensitivity of model results to plume buoyancy. During the site visit, condensed steam plumes extending vertically to approximately 50 metres on a cold calm morning clearly indicated the role of buoyant plume rise, especially when ambient temperatures are low. A second area of impact, to the south of the plant, does not relate well to the model output. It is likely that the odour impact in this area is underpredicted, for one or both of two main reasons. Firstly, the relevant conditions as indicated by TOU involve a shallow and localised drainage flow, which may not be resolved by the model. In that case, its impact would not be indicated by the concentration contours. Secondly, the impacts may be significantly influenced under some circumstances by livestock odours from the holding yards, which are not included in the modelling. Hence, the model results in this area may not be a useful guide to arriving at an odour threshold.

On the basis of the discussion in the above paragraph, the modelled odour concentrations in Figure 8.9 and Figure 8.10 are evaluated in relation only to the impact area highlighted to the west of the plant. In that area $C_{99.0\ 1\text{-hr}}$ values are approximately 1.5 - 4 ou, and $C_{98\ 1\text{-hr}}$ values of about 0.8 - 2 ou.

In arriving at a suitable odour criterion for this site, consideration also needs to be given to the relatively small population in the surrounding area, and the lack of detailed quantitative data on complaints and the circumstances under which they have occurred.

Notwithstanding these issues, the results would suggest that the $C_{99.0\ 1\text{-hr}}$ value should not exceed approximately 1.5 ou, or somewhat less, and the $C_{98\ 1\text{-hr}}$ should be no more than about 0.8 ou.

9.3 Plant 3

The model results for the Plant 3 rendering odours are shown in Figure 8.11 and Figure 8.12. These figures identify three areas of impact:

- to the north and northwest, upslope in the neighbouring residential estate;
- at isolated houses downslope to the east, probably impacted during drainage flow conditions;
- at an isolated house to the south, at a lower elevation.

The facility is located near the end of a ridge, with a creek valley running to the west and northeast, and a larger valley to the south through east. Accordingly, local flow patterns are likely to be complex at times, especially under stable atmospheric conditions with light winds. Complex local flows were observed during the 20 June 2002 site visit. It is unlikely that the full complexity of local flows has been captured by the models. In such situations, some additional measurements are required to generate the necessary detailed data to supplement the prognostic model simulations.

Similarly to the other sites, there is an absence of detailed information about the frequency, timing, weather conditions and other circumstances associated with complaints. Hence, only broad conclusions can be drawn from the available information.

A feature of the odour observations at this facility was the detection of livestock odours at similar distances from the source to the rendering odours. Both odour sources are included in the modelling, but there is an issue with simply combining the odours linearly, as the interaction may be non-linear, particularly in terms of perceived odour strength.

Another item of potential importance to long-term modelling for the site was the condition of the biofilter at the time of the site visit. Although TOU had not noticed serious problems on previous visits, the biofilter on 20 June 2002 was operating poorly, with elevated odour emissions due to patches of dry filter medium. The modelling is based on a properly functioning biofilter but the observations on site showed that even small areas of dry medium can greatly increase the total odour emission rate. If such problems have occurred from time to time, then the relationship between complaints and modelled odour levels may be unrepresentative.

Based on the model results in Figure 8.11 and Figure 8.12, drainage flows to the east of the plant may not be well simulated. However, on face value, the model results indicate that issues arise if the $C_{99.0\ 1\ hr}$ is above about 2 ou and the $C_{98\ 1hr}$ is above about 1 ou.

10 CONCLUSION

There are significant sources of uncertainty associated with the modelling and the analysis of odour levels associated with the onset of complaints. A lack of detailed complaints data, an absence of detailed meteorological data from multiple sites and an inability to perform detailed model validation all contribute to a lack of precision in the final analysis of odour levels against complaints. Furthermore, suitable odour criteria should aim to substantially reduce the likelihood of annoyance, and not simply aim to limit complaints. Annoyance criteria cannot be directly established from the available information. However, despite these limitations, the results of the study do yield approximate odour criteria that should be regarded as a useful, if interim, benchmark.

From the available information, presented and discussed in earlier sections, indicative odour thresholds have been identified, and are presented in Table 10.1.

Table 10.1: Summary of Complaint Threshold Criteria Derived from Results of Study

Site	$C_{99.5\ 1hr}$ (ou)	$C_{99\ 1hr}$ (ou)	$C_{98\ 1hr}$ (ou)
Plant 1	2	-	1
Plant 2	-	1.5	0.8
Plant 3	-	2	1

From Table 10.1, it can be seen that the derived criteria for all sites are similar. Note that the $C_{99\ 1hr}$ value is always smaller than the $C_{99.5\ 1hr}$ value, and is intermediate between the $C_{99.5\ 1hr}$ and $C_{98\ 1hr}$ values.

The criteria listed in Table 10.1 relate only to the lower odour limit associated with areas where complaints have occurred.

To compare the results with other benchmarks, the Queensland EPA has been developing a new odour policy, and recent advice indicated that a $C_{99.5\ 1\text{-}hr}$ criterion of 1 ou was proposed to protect against nuisance. The derived complaint threshold criterion of 2 ou ($C_{99.5\ 1\text{-}hr}$) in Table 10.1 may be reasonably consistent with that draft policy position, allowing for the different end-points being considered (i.e., annoyance vs complaint). However, it is evident that odour levels associated with annoyance and complaint can differ markedly from site to site, depending on odour type and exposure characteristics (essentially the FIDOL factors discussed in 0), as well as a raft of 'soft' factors that reflect community and individual factors (Ormerod *et al*., 2003a).

The $C_{99\ 1\text{-}hr}$ results for the NSW sites in Table 10.1 can be compared to the NSW planning criteria (converted approximately to a 1-hr averaging period) of 0.9 to 3 ou, depending on exposed population (see Table 4.2).

Based on the results discussed above, compliance criteria suitable to avoid significant risk of serious annoyance due to rendering plant odours are suggested as in Table 10.2. These values apply a margin of safety to the values listed in Table 10.1.

Table 10.2: Summary of Interim Compliance Odour Criteria to Avoid Significant Annoyance

Indicator	Odour Concentration (ou)
$C_{99.5\ 1hr}$	1.5
$C_{99\ 1hr}$	1
$C_{98\ 1hr}$	0.5

Note that an equivalent $C_{99\ 1\text{-}s}$ value, based on a peak-to-mean ratio of 2.3 (NSW EPA, 2001), would be approximately 2.3 ou.

It should be noted that the suggested criteria are based on limited data, and hence warrant closer study. An appropriate study approach, based on the known limitations of the data used for this study, would include the use of specific odour complaints or observations made by residents in odour diaries, to permit closer examination of the links between annoyance, complaint and odour concentration. Also, it is critically important that emission rate variations and source details including plume buoyancy effects are properly incorporated into any modelling of odour dispersion from rendering plants.

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Appendix A

Wind Rose Diagrams for Plant 2, Plant 3 and Plant 1

The wind roses show the frequency of occurrence of winds by direction and strength. The bars correspond to the 16 compass points – N, NNE, NE, etc. The bar at the top of each wind rose diagram represents winds blowing from the north (i.e., northerly winds), and so on. The length of the bar represents the frequency of occurrence of winds from that direction, and the widths of the bar sections correspond to wind speed categories, the narrowest representing the lightest winds. Thus it is possible to visualize how often winds of a certain direction and strength occur over a long period, either for all hours of the day, or for particular periods during the day. Note that the wind rose data are extracted from a model, and therefore this represents an estimate of the local conditions.

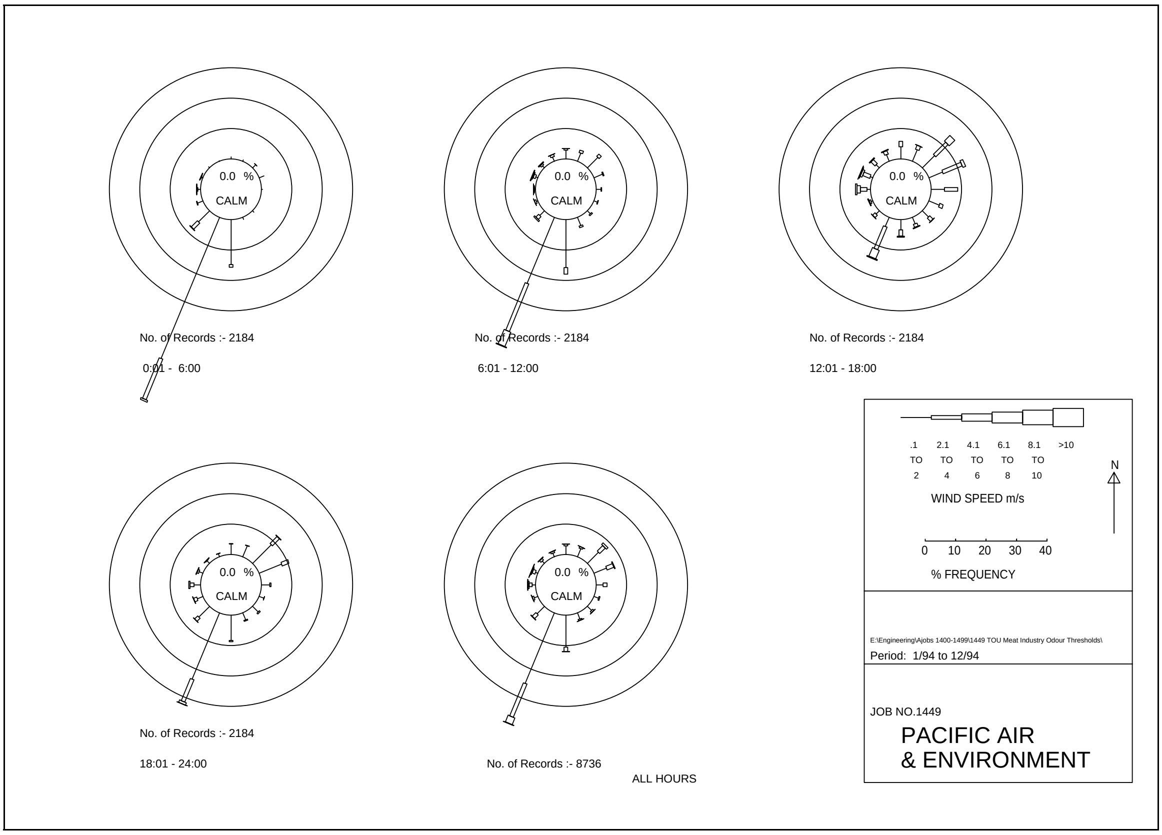

Figure 11.1: Wind Rose for Plant 1 - Locality 1

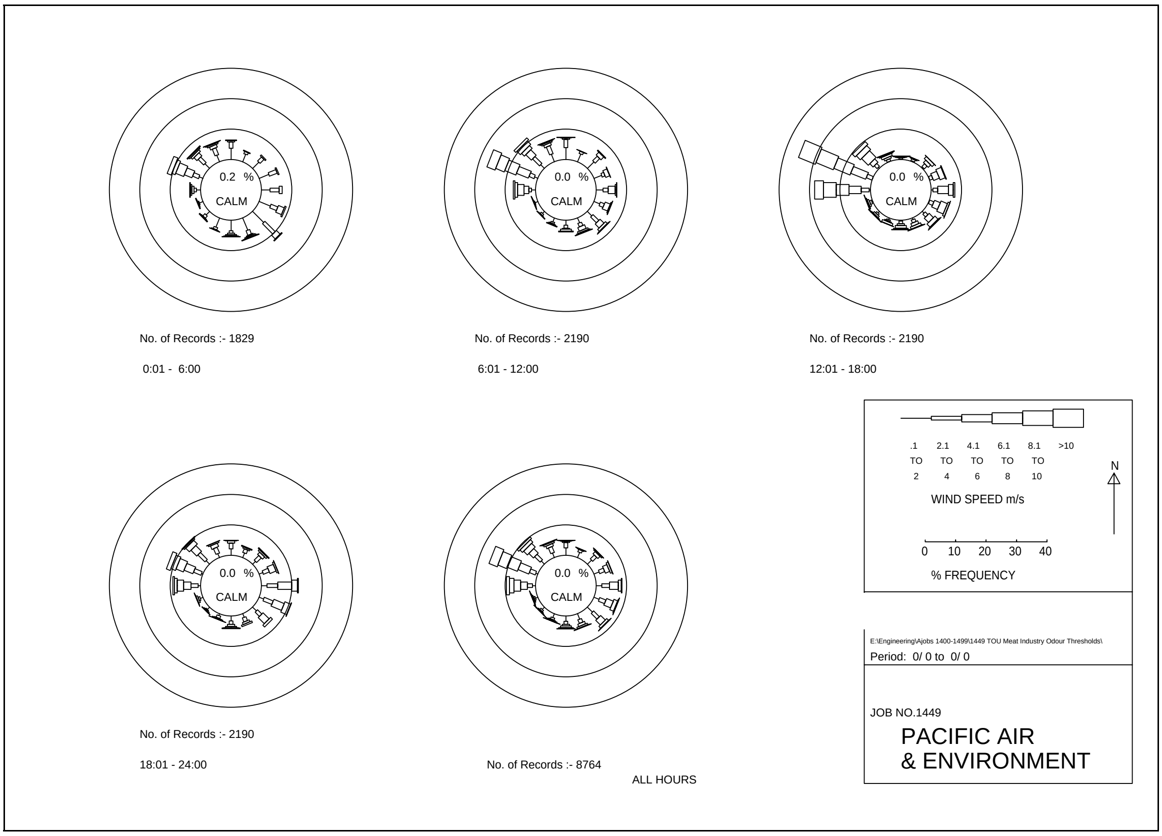

Figure 11.2: Wind Rose for Plant 3 – Locality 3

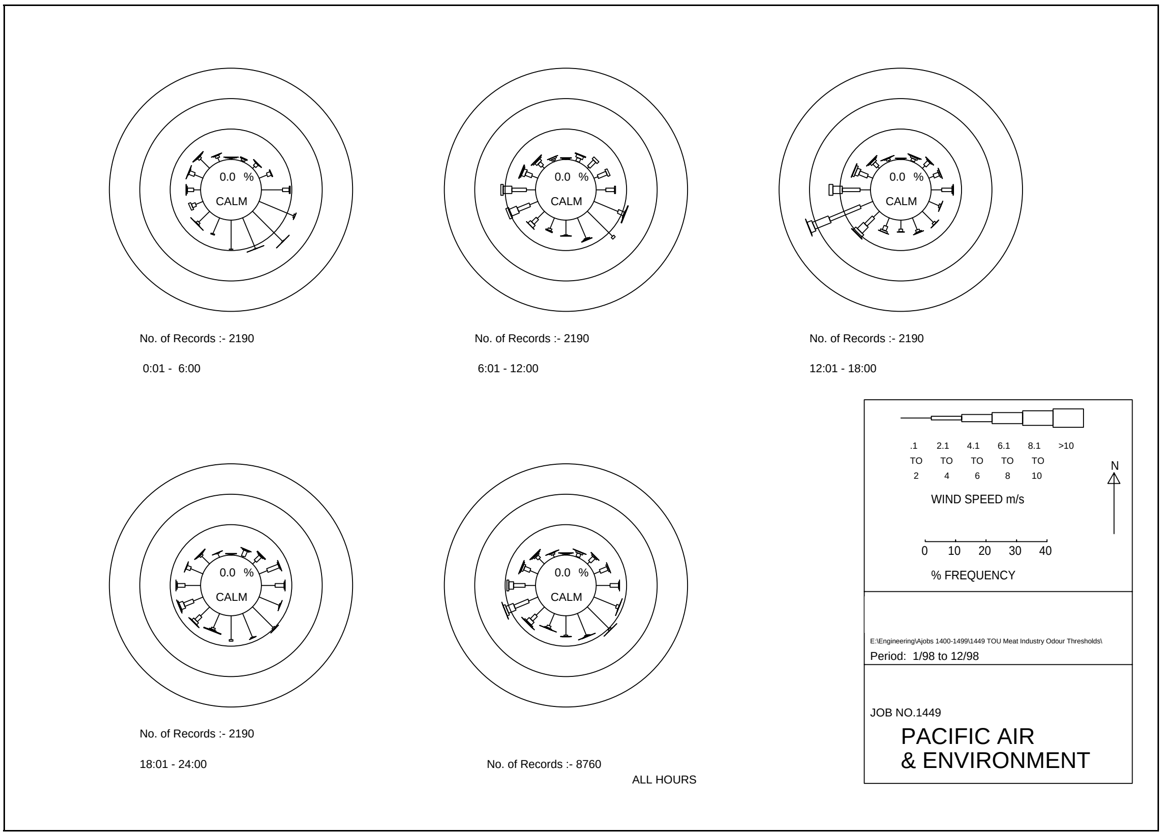

Figure 11.3: Wind Rose for Plant 2 – Locality 2

Appendix B

Analysis of Odour Intensity Field Observations
Background Information

Using VDI 3940 in field observations

VDI 3940 describes a procedure for logging odour in the field, involving noting the odour intensity every 10 seconds over a 10 minute period. The method is employed over a grid of points on the ground at various times throughout a year, in order to determine the number of ‘odour hours’, which form the basis of determining acceptability. An odour hour occurs when the specific odour in question is clearly recognisable for at least 10% of the sample period, i.e., at least 6 of the 60 observations over a 10-minute period. Over a year, the odour is considered to be unacceptable if odour hours occur for more than 10% of the time, i.e., more than 876 hours in a year. Where observations are not possible to prove this, a modelling procedure is also allowed, and it involves the routine application of a factor of 10 to modelled 1-hour odour concentrations to account for odour fluctuations (Frechen, 1997). Effectively, the odour hour approach equates to a nose-response-time averaged odour concentration equivalent to the intensity of weak or distinct odour on the VDI scale, occurring at a frequency of at least 1% of the time over the whole year. (A clearly recognisable odour is assumed to equate to either weak or distinct on the VDI scale).

Observations of odour intensity in the field for the three rendering facilities are only loosely based on the German approach because the objectives are not identical. Observations are made at various locations downwind of the plants. However, rather than defining ‘odour hours’, the procedure is based on using the observed odour intensity measurements as a basis for estimating mean and peak odour concentrations and peak-to-mean ratios, and for relating the field observations to odour complaints and other reports. The observations also provide a basis for ground-truthing of model simulations of odour concentration.

Most observing periods are of 30 minutes or greater in order to obtain a more representative sample of the fluctuations in odour intensity than is required in the German odour hour approach.

The odour intensity observations are made every 10 seconds (within a margin of error estimated to be typically ±10%), but the actual sampling of odour occurs only during inhalation, which typically has a duration of about 2 seconds. Thus, the odour data represent 2-second average samples once every 10 seconds.

Analysis of odour intensity field observations

An important aim of the odour intensity observations is to provide data from the field that might assist in odour dispersion model evaluation. The method of analysing the data for this purpose is described below.

The odour intensity for each sample is equated to an odour concentration, based on a relationship such as that represented in Figure 8.5. Because the odour intensity scale is categorical or integer based and not continuous, it is not necessarily correct to equate an odour intensity scale value to a single fixed odour concentration. For example, an intensity value of 3 may appear to be equal to an odour concentration of 4.75 ou. However, when an observer in the field correctly classes an odour as having an intensity scale value of 3, then the actual odour concentration may be in the range between approximately 2.5 and 9 ou. The values of 2.5 and 9 ou represent the midpoints between intensity scale values 2 and 3 (i.e., 2.5), and 3 and 4 (i.e., 3.5), respectively. Thus, when relating the odour intensity scale value of 3 to an odour concentration for the purpose of analysis, the true odour concentration may correspond to an intensity value anywhere between 2.5 and 3.5 (i.e. between 2.5 and 9 ou).

In order to represent this uncertainty in the analysis of the field data, consider each observation period as comprising a series of odour intensity samples I_k, where I refers to intensity, k = 1 to n and n = 180 for a standard 30-minute observing period. Each intensity sample I_k has an integer value in the range 0 to 6. For each recorded intensity sample I_k the corresponding randomised value of odour intensity I_{kR} is calculated as follows:

$$I_{kR} \qquad = I_L + X$$

where:

I_{kR} = the randomised value of I_k

$I_L = I - 0.5$ = the lower bound odour intensity value for the intensity class I (e.g. the value of I_L for $I = 3$ is 2.5)

X = a random number between 0 and 1, generated separately for each of the n samples in the observation series

Hence, each recorded odour intensity scale value I_k that occurs in a series of observations is converted to a randomised odour intensity value I_{kR} in the specified range I_L to I_U (where $I_U = I + 0.5$) for that intensity value. This analysis typically yields different concentration values each time the same set of intensity data is analysed. This occurs as a result of using random numbers (X) in the estimation procedure to permit the translation from a categorical integer scale (intensity) to a continuous scale (concentration).

Table B.11.1 provides the values of I_L and I_U for each intensity scale value. For example, it is assumed that intensity class 1 values are randomly distributed in the range 0.5 to 1.5 (i.e. I +/- 0.5). Therefore, over a large number of data points (i.e. large sample size), the mean odour intensity for intensity class 1 will tend to 1 as expected. Note, however, that in relation to intensity scale value 0, while it is assumed that the intensity values are randomly distributed between –0.5 and 0.5 (i.e. to ensure an even distribution), all negative intensity values are set to 0 prior to the derivation of any odour concentration values.

Table B.11.1: Parameters for Intensity-Concentration Relationship

Intensity Class (I)	Lower Bound Intensity Value (I_L)	Upper Bound Intensity Value (I_U)
0[a]	-0.5	0.5
1	0.5	1.5
2	1.5	2.5
3	2.5	3.5
4	3.5	4.5
5	4.5	5.5

a The lower limit of -0.5 is only used for the randomisation process, with all randomised intensity values less than zero then set to zero. Thus, no negative intensity values are used in the final assessment process.

Performing a large number of parallel analyses of the intensity data series provides a large set of results. For this study, Monte Carlo simulation converts each intensity observation series I_k (k = 1 to n) to 100 different simulated odour intensity series I_{kR} (k = 1 to n).

Once the 100 simulations have been derived, they are then converted to odour concentration values. This is performed using the following relationship:

$$I_{kR} = 0.947Ln(C_{kR}) + 1.74$$

where:

C_{kR} = Odour concentration derived from the value of I_{kR} (k = 1 to n) (ou)
I_{kR} = Randomised odour intensity value based on the value I_k (k = 1 to n) recorded by the field observer

The final result is the generation of 100 simulated odour concentration series, with different estimates of mean and maximum odour concentrations compared with the original intensity series (i.e., as measured in the field). The results of all simulated concentration series are then summarised to provide a range of estimated mean and maximum odour concentrations, as well as maximum-to-mean ratios, for the relevant observation period. The maximum-to-mean ratio derived by this method is similar in magnitude, but not equivalent, to the peak-to-mean ratio as described by NSW EPA (2001). By definition, the estimated maximum-to-mean ratio will be smaller than the peak-to-mean ratio, but owing to the uncertainties inherent in both ratios, they are assumed to be approximately equivalent and no conversion factor is applied.

The analytical procedure described above allows inherent uncertainty in the data to be recognised and, if necessary, quantified.

The results of the analysis are plotted as time series and as scatter plots showing the results of the mean vs. peak concentrations and of the mean vs. maximum-to-mean ratios (also referred to as peak-to-mean ratios, notwithstanding the caveats noted above) for each of the 100 simulations. These scatter plots visually display the uncertainty inherent in the estimated concentration data. Examples appear below:

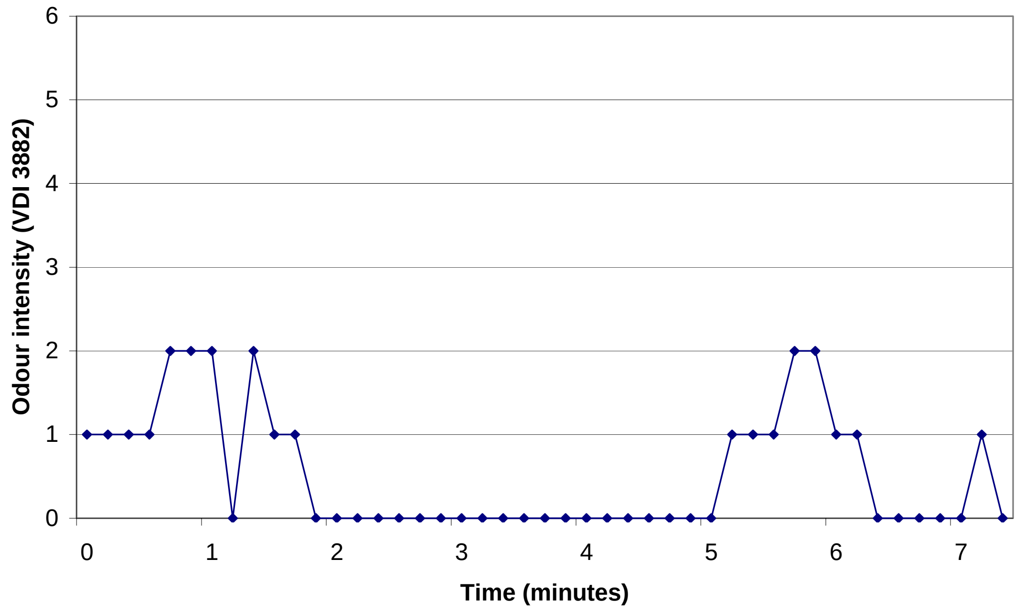

Figure 11.4: Odour Intensity Time Series, Plant 3 Site C1

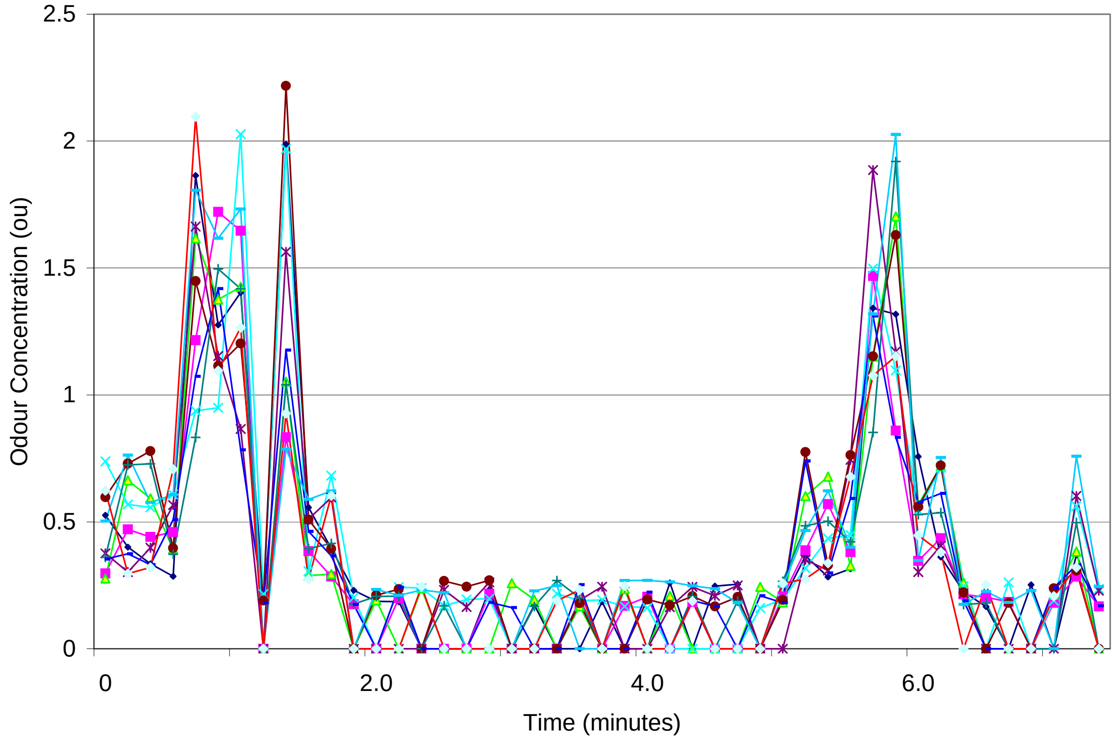

Figure 11.5: Odour Concentrations Time Series, Plant 3 Site C1

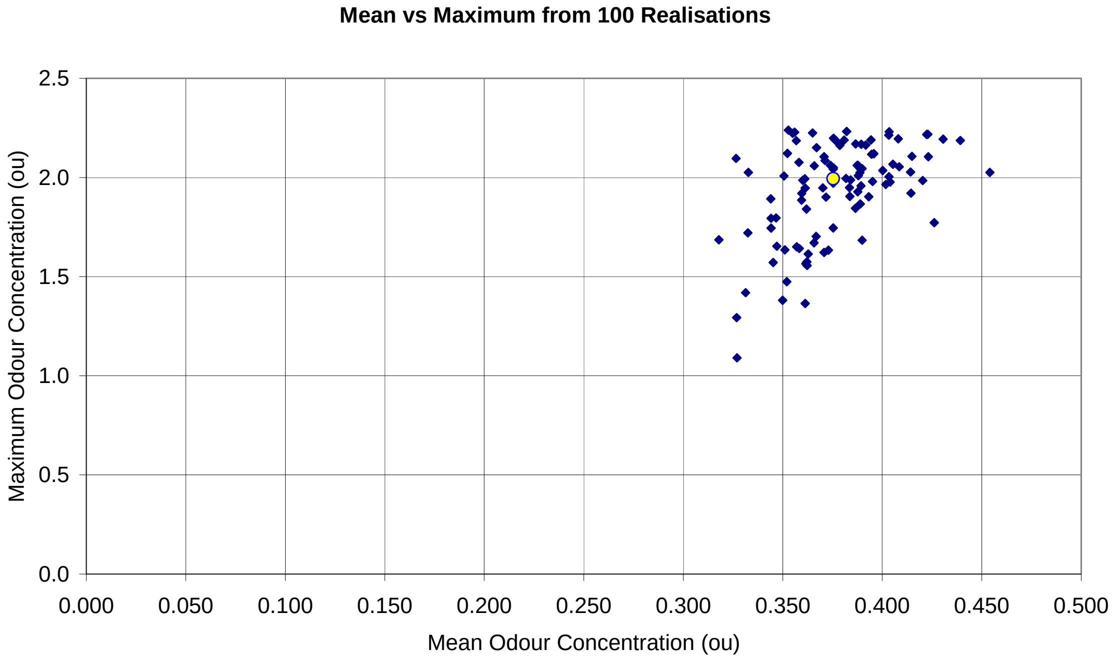

Figure 11.6: Mean vs Maximum Odour Concentration, Plant 3 Site C1

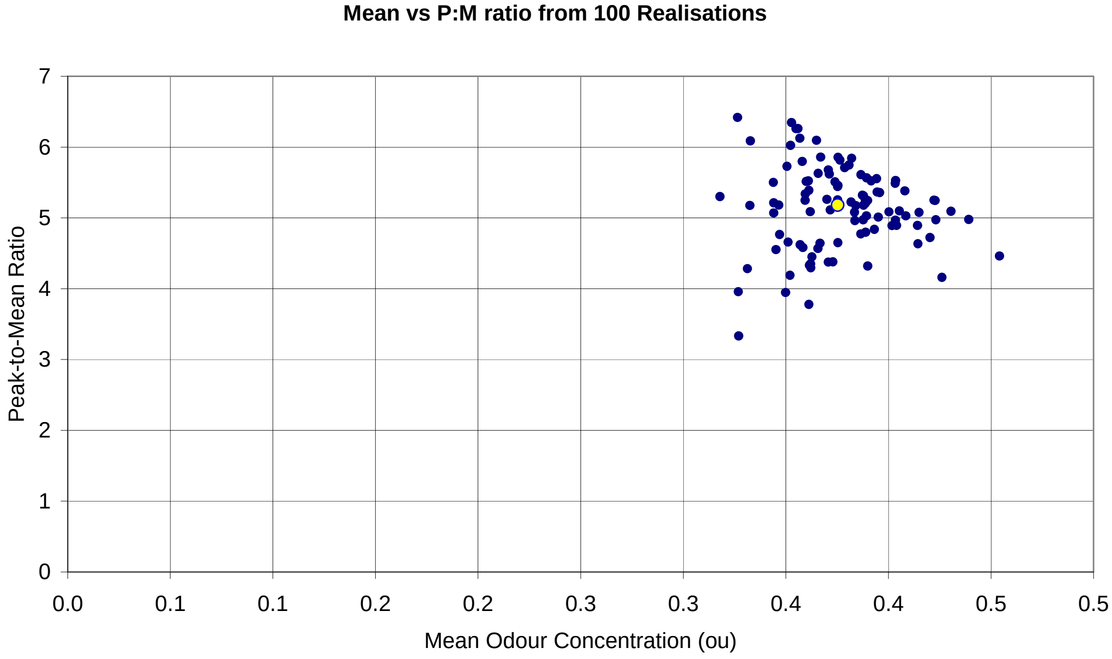

Figure 11.7: Mean vs Peak: Mean Odour Concentration, Plant 3 Site C1

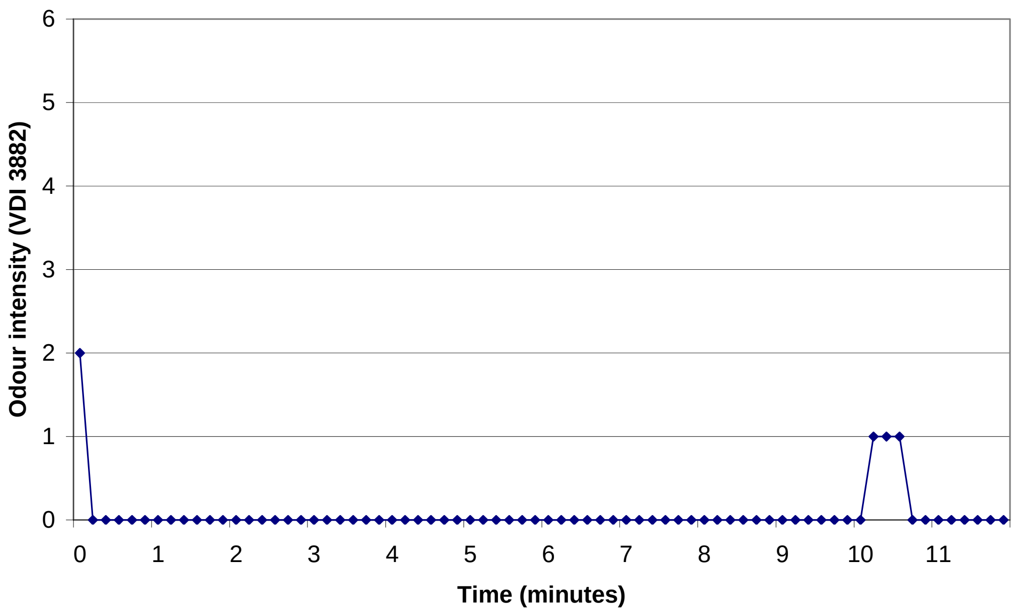

Figure 11.8: Odour Intensity Time Series, Plant 3 Site C2

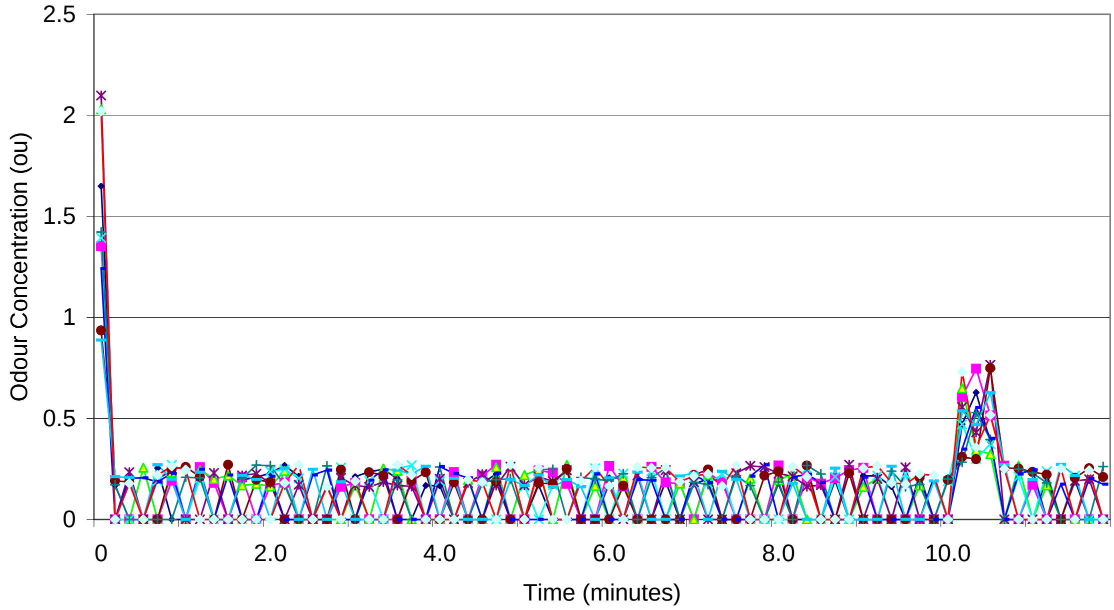

Figure 11.9: Odour Concentrations Time Series, Plant 3 Site C2

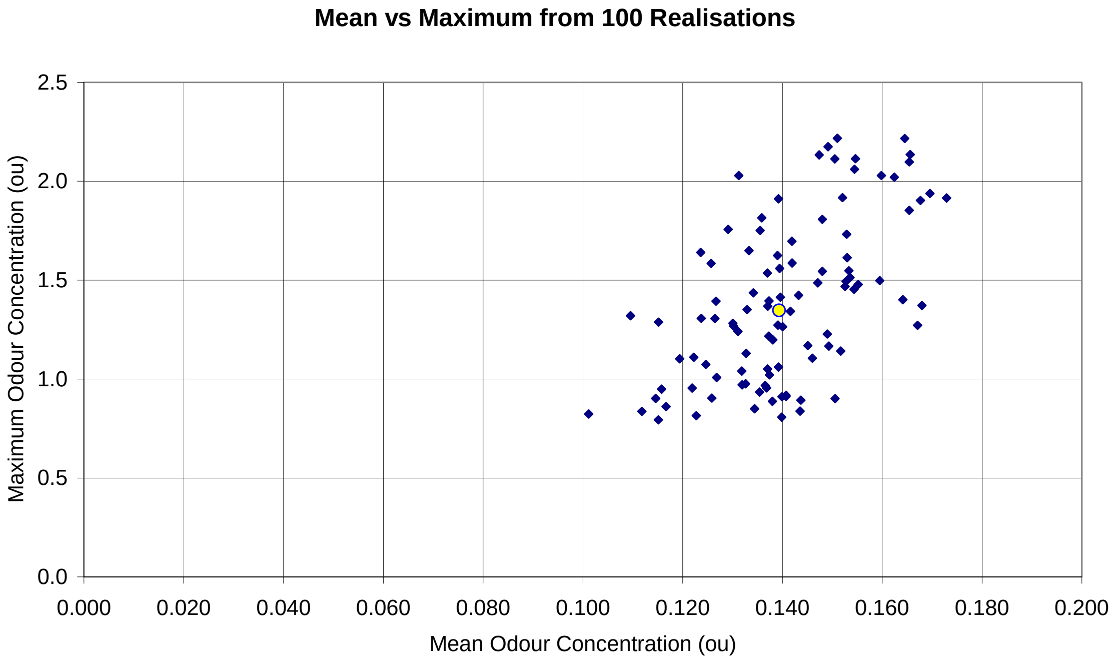

Figure 11.10: Mean vs Maximum Odour Concentration, Plant 3 Site C2

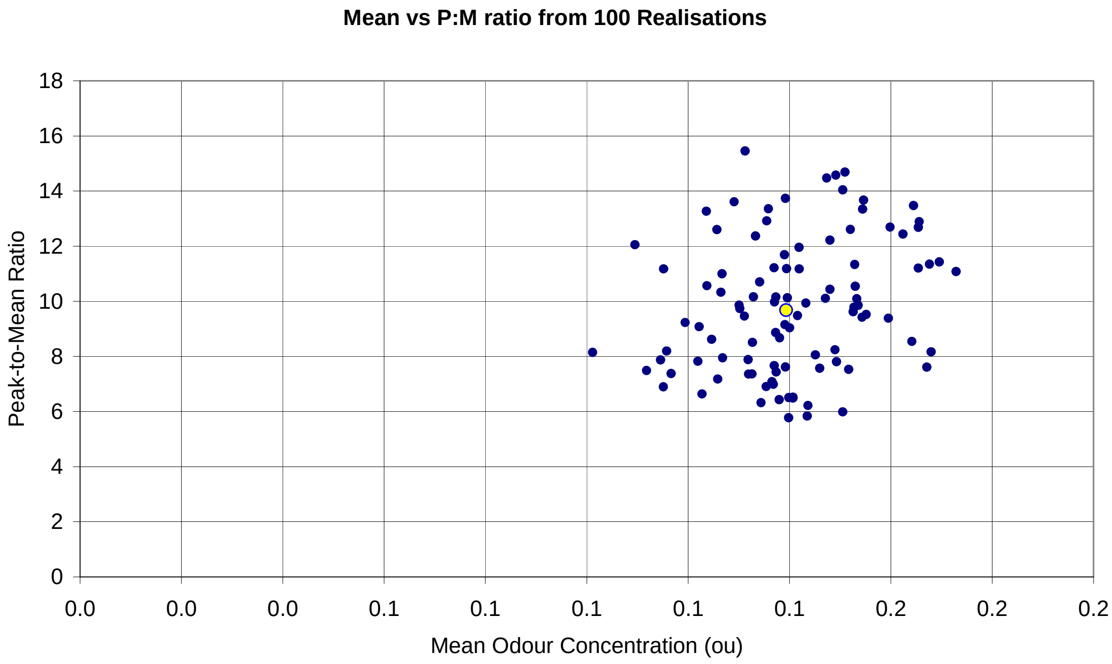

Figure 11.11: Mean vs Peak:Mean Odour Concentration, Plant 3 Site C2

Appendix C

Dispersion Modelling Results using Ausplume

Plant 1

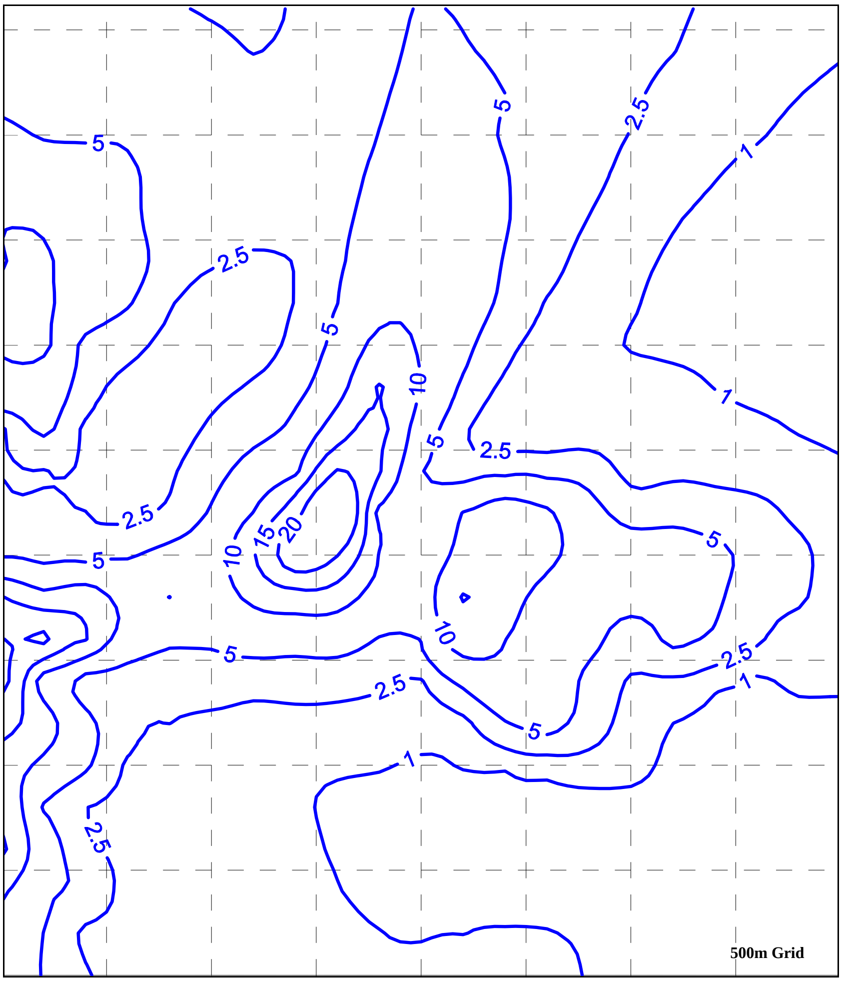

Figure 11.12: $C_{99.5\ 1\text{-hr}}$ Rendering Odour Concentration (ou) – Plant 1

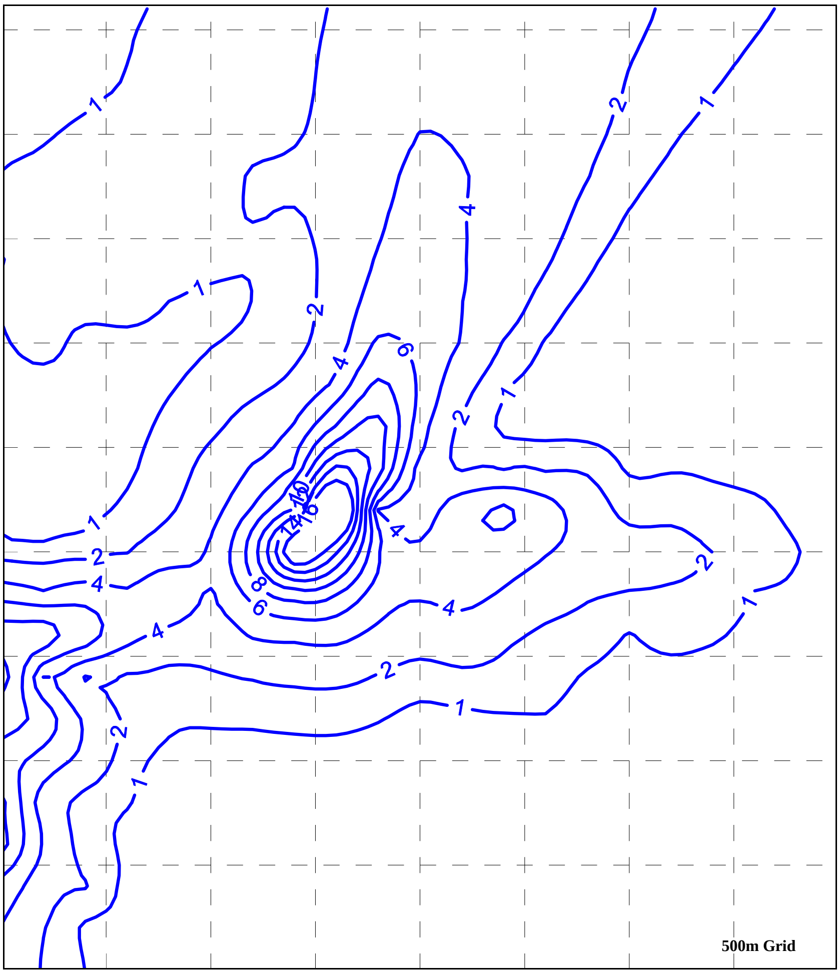

Figure 11.13: $C_{98\ 1\text{-hr}}$ Rendering Odour Concentration (ou) – Plant 1

Plant 2

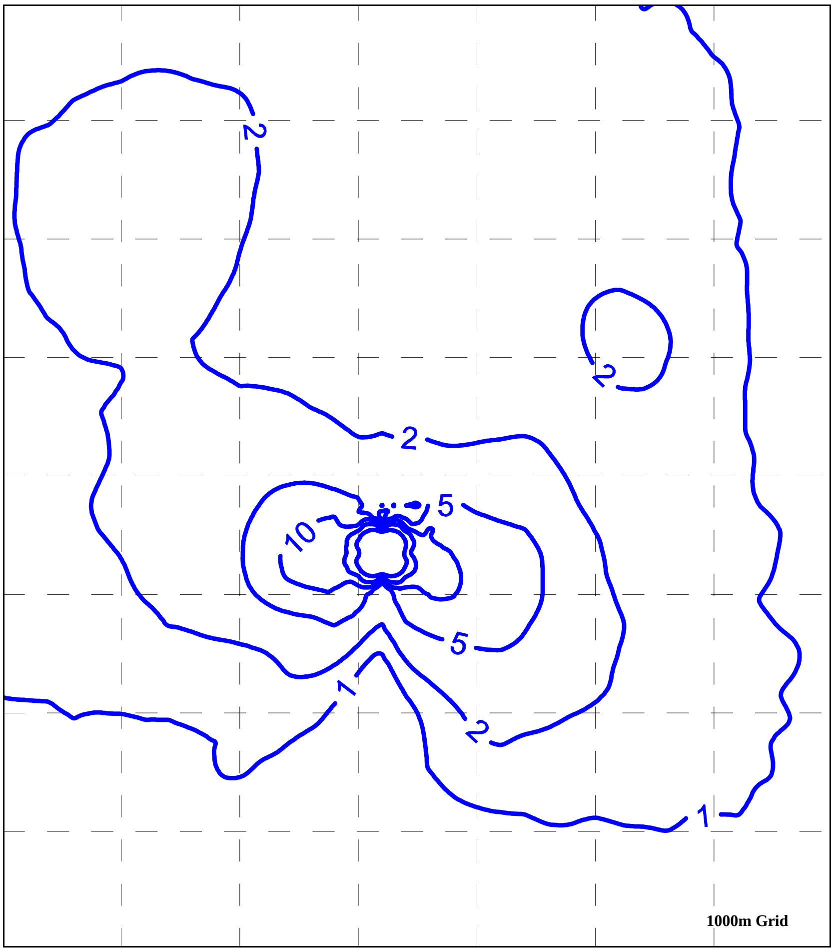

Figure 11.14: $C_{99\ 1\text{-}hr}$ Rendering Odour Concentration (ou) – Plant 2

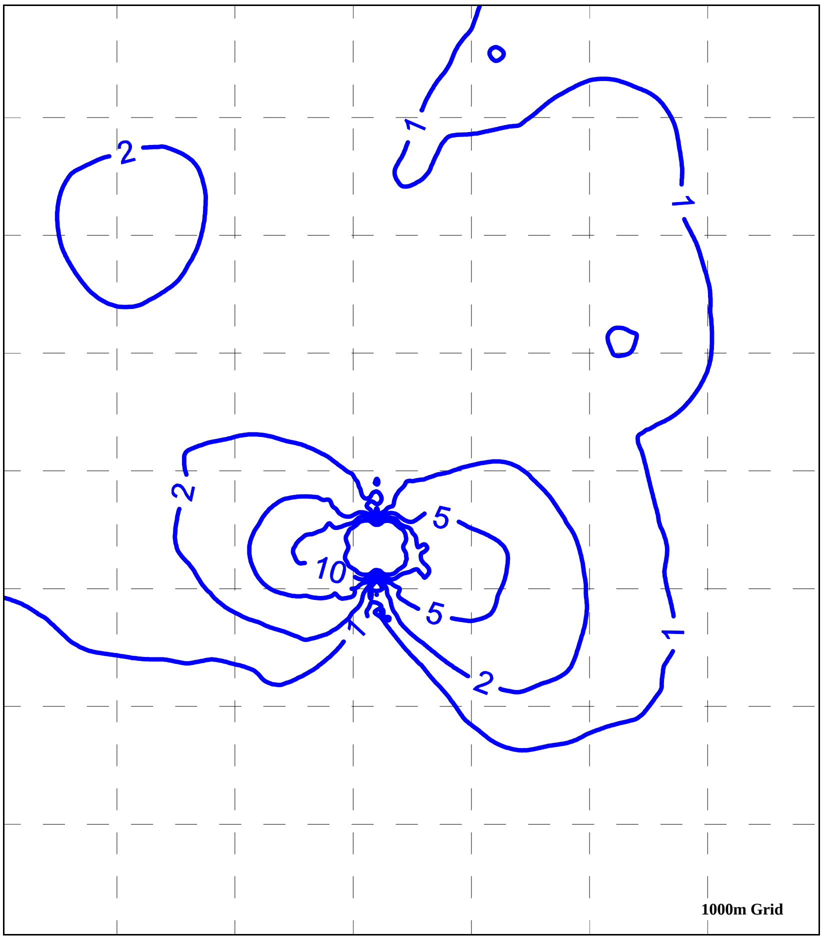

Figure 11.15: $C_{98\ 1\text{-hr}}$ Rendering Odour Concentration (ou) – Plant 2

Plant 3

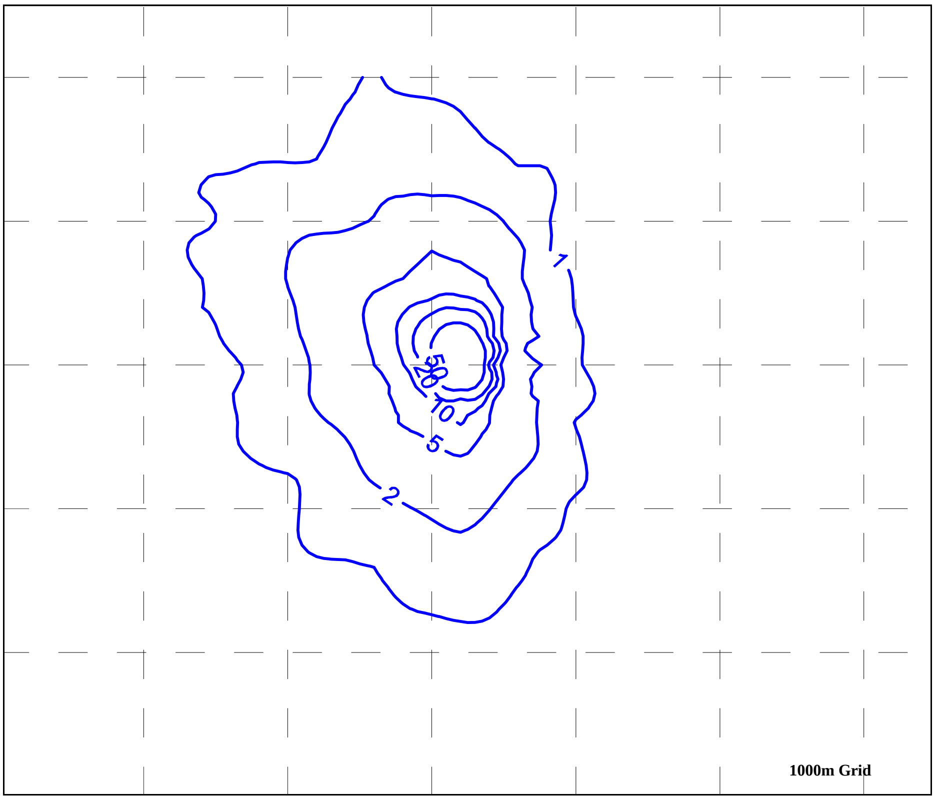

Figure 11.16: $C_{99\ 1\text{-}hr}$ Rendering Odour Concentration (ou) – Plant 3

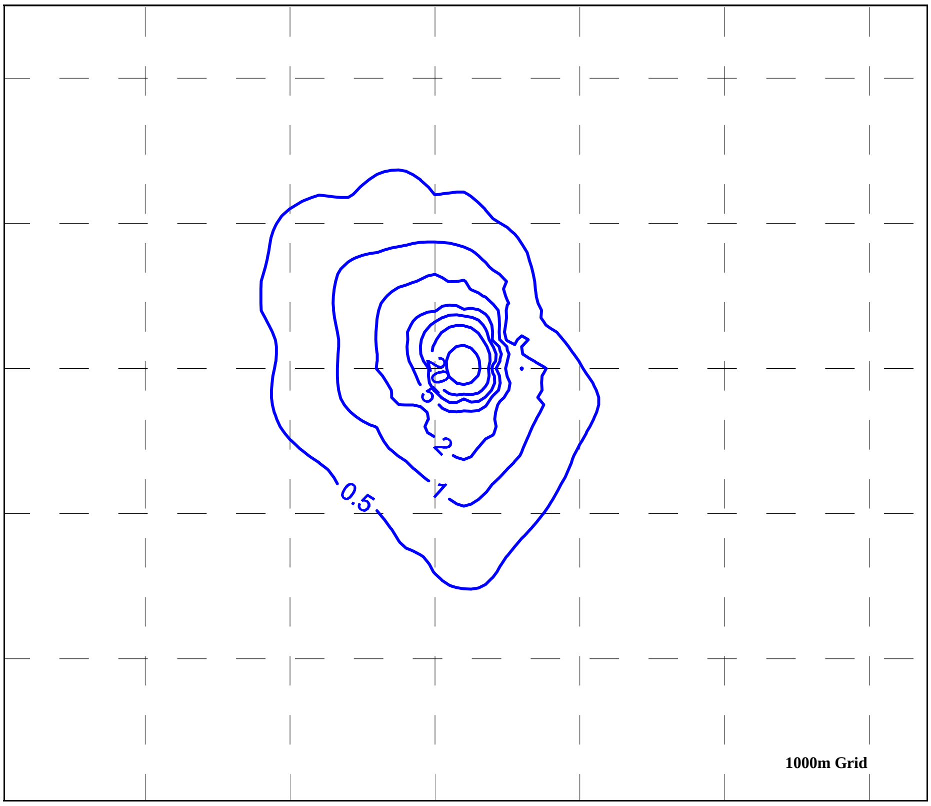

Figure 11.17: $C_{98\ 1\text{-}hr}$ Rendering Odour Concentration (ou) – Plant 3